TeXQuery: A Full-Text Search Extension to XQuery

Part II – Formal Semantics

Sihem Amer-Yahia [1]
sihem@research.att.com

Chavdar Botev [2]
cbotev@cs.cornell.edu

Jonathan Robie [3]
jonathan.robie@datadirect-technologies.com

Jayavel Shanmugasundaram [2]
jai@cs.cornell.edu

[1] AT&T Labs
[2] Computer Science Department, Cornell University
[3] DataDirect Technologies

14 July 2003

Contents

1. Introduction

This document describes the formal semantics of the TeXQuery extension to XQuery. As discussed in Part I – Language Specification and shown in Figure 1, *FTSelection*s are the basic expression in a full-text query. *FTSelection*s are fully composable in the sense that each *FTSelection* operates on zero or more *FullMatch*es and returns a *FullMatch*. Regular XQuery expressions can be nested inside *FTSelection*s, and *FTSelection*s can themselves be nested inside regular XQuery expressions.

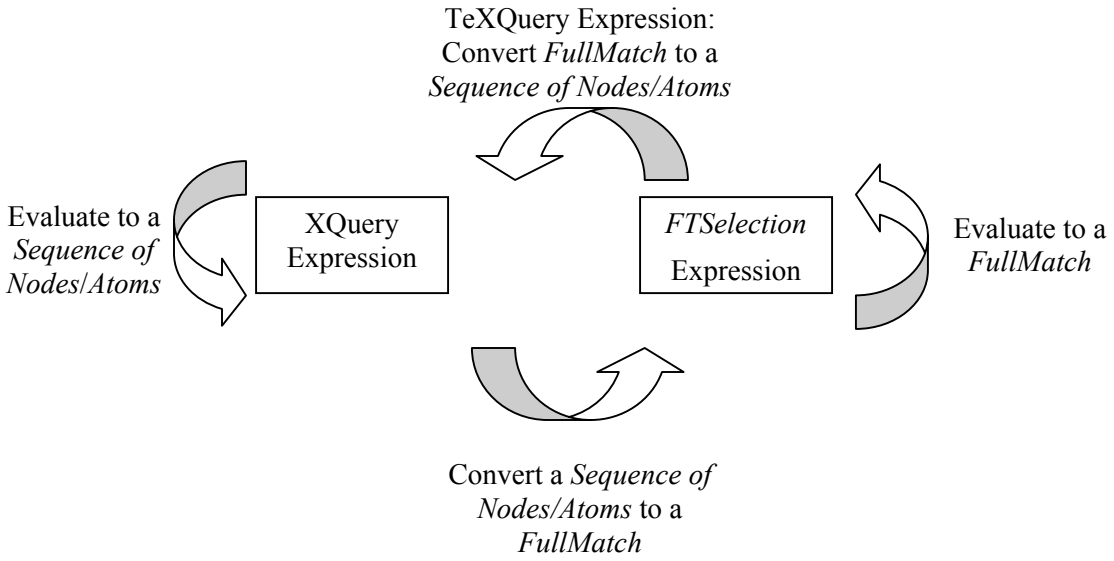


Figure 1 Composing XQuery and TeXQuery expressions

Given the above relationship between XQuery expressions and *FTSelection*s, this formal semantics document addresses the following issues. First, it defines the semantics of XQuery expression nested in *FTSelection*s (bottom arrow in Figure 1). Second, it defines the notion of a *FullMatch* and specifies how each *FTSelection* operates on zero or more *FullMatch*es and returns a *FullMatch* (right arrow in Figure 1). Finally, it specifies how TeXQuery expressions convert a *FullMatch* to a sequence of nodes/atoms in the XQuery data model (top arrow in Figure 1). The semantics of XQuery expressions (left arrow in Figure 1) is specified in the XQuery semantics document [1] and is not discussed here.

The rest of this document is organized as follows. In Section 2, we specify the semantics of nesting XQuery expressions in *FTSelection*s. In Section 3, we describe the *FullMatch* data model. In Section 4, we describe how TeXQuery expressions convert a *FullMatch* to a sequence of nodes/atoms. In Section 5, we specify the semantics of *FTSelection* expressions. First (5.1), the general FTSelection expression semantics is described. Then in 5.2, we present the semantics of individual FTSelection expressions. Finally, in Section 6, we present a complete example that illustrates the main points from the previous sections.

2. Nested XQuery Expressions in FTSelections

The semantics of XQuery expressions nested inside FTSelections is given below.

2.1. FTStringSelection

The XQuery expression nested inside an *FTStringSelection* must evaluate to a sequence of string values after applying *atomization* [1] (otherwise the entire *FTSelection* returns an error). The sequence of strings is used as described in Part I.

2.2. FTRangeSpec

The XQuery expression (or expressions, in the case of a "from-to" range) must evaluate to a singleton sequence of integers after applying *atomization* [1] (otherwise the entire *FTSelection* returns an error). The resulting integer values are treated as boundaries for the corresponding range as described in Part I.

2.3. FTStopWordsCtxMod

The XQuery expression must evaluate to a sequence of string values after applying *atomization* [1] (otherwise the entire *FTSelection* returns an error). The resulting string values are treated as stop words that must be ignored during phrase matching and proximity evaluation as discussed in Part I.

2.4. FTThesaurusCtxMod

The XQuery expression sub-expression must evaluate must evaluate to a sequence of string values after applying *atomization* [1] (otherwise the entire *FTSelection* returns an error). The resulting string values are treated as names of thesauri to use during string matching as discussed in Part I.

2.5. FTLanguageCtxMod

The XQuery sub-expression must evaluate to either an empty sequence or a singleton sequence of a string value or an empty sequence after applying *atomization* [1] (otherwise the entire *FTSelection* returns an error). The resulting string value is treated as a language identifier specifying the language of the matched document/documents as discussed in Part I.

2.6. FTIgnoreCtxMod

The XQuery sub-expression must evaluate to a sequence of element nodes (otherwise the entire *FTSelection* returns an error). The resulting element nodes define the nodes whose element tags/content must be ignored as discussed in Part I.

3. The FullMatch Data Model

As described in Part I, the XQuery data model of a "sequence of nodes" is inadequate for fully composable *FTSelection*s. The main reason is that full-text operations (such as *FTSelection*s) operate on linguistic tokens, such as positions of words, and such information is not captured in the XQuery data model. We thus define the *FullMatch* data model that allows for fully compositional *FTSelection*s. Before formally defining the *FullMatch* data model, we first describe the key concept of a position.

3.1. Positions

A position is the identity of a linguistic token inside an XML document. Each position is associated with:

- the linguistic token it identifies,
- the relative position of the linguistic token in the document,
- the relative position of the sentence containing the linguistic token
- the relative position of the paragraph containing the linguistic token
- the node that directly contains the linguistic token, and
- where the linguistic token appears in the node containing it (i.e., tag name, element content, etc.)

As an illustration, consider the following XML fragment:

```
<offer id="1000" price="10000">
   Ford Mustang 2000, 65K, excellent condition, runs great, AC,
   CC, power all
</offer>
<offer id="1001" price="8000">
   Honda Accord 1999, 78K, A/C, cruise control, runs and
   looks great, excellent condition
</offer>
<offer id="1005" price="5500">
   Ford Mustang, 1995, 150K highway mileage, no rust, excellent
   condition
</offer>
```

If we assume that linguistic tokens are delimited by punctuation and whitespace symbols (in English), the first linguistic token "offer" (the element tag name) will be assigned a relative position of 1, the linguistic token "id" (the attribute name) will be assigned a relative position of 2, the linguistic token "100" (the value of attribute id) will be assigned a relative position of 3, and so on. The relative positions of the linguistic tokens are shown below in parenthesis.

```
<offer(1) id(2)="1000(3)" price(4)="10000(5)">
   Ford(6) Mustang(7) 2000(8), 65K(9), excellent(10)
condition(11), runs(12) great(13), AC(14), CC(15),
power(16) all(17)
</offer(18)>
<offer(19) id(20)="1001(21)" price(22)="8000(23)">
```

```
   Honda(24) Accord(25) 1999(26), 78K(27), A(28)/C(29),
cruise(30) control(31), runs(32) and(33) looks(34)
great(35), excellent(36) condition(37)
</offer(38)>
<offer(39) id(40)="1005(41)" price(42)="5500(43)">
   Ford(44) Mustang(45), 1995(46), 150K(47) highway(48)
mileage(50), little(60) rust(61), excellent(62)
condition(63)
</offer(64)>
```

The relative positions of paragraphs are determined similarly. Assuming that the paragraph delimiters are start tag ("<"), end tag (">"), and end of line characters, the first tag will be assigned a paragraph relative number 1, the following element content will be assigned a relative number 2, the end tag will be assigned relative number 3, and so on.

The relative positions of sentences are also determined similarly using sentence delimiters such as ".", "!", and "?".

3.2. FullMatch

We now define a *FullMatch*. Intuitively, a *FullMatch* specifies the positions that a node should contain, and the positions that a node should not contain, in order to satisfy an *FTSelection*. We first introduce a *FullMatch* using some examples and intuition. We then formally define a *FullMatch*.

3.2.1. Examples and Intuition

Consider the *FTStringSelection* "`Mustang`" evaluated over the sample document fragment in the previous section. The *FullMatch* corresponding to this *FTStringSelection* is shown in Figure 2. As shown, the *FullMatch* consists of two *SimpleMatch*es. Each *SimpleMatch* represents one possible "solution" to the *FTStringSelection* "`Mustang`". The "solution" to the first *SimpleMatch* are those nodes that contain (represented as *StringInclude*) the linguistic token "Mustang" at position 7. The "solution" to the second *SimpleMatch* are those nodes that contain the linguistic token "Mustang" at position 45.

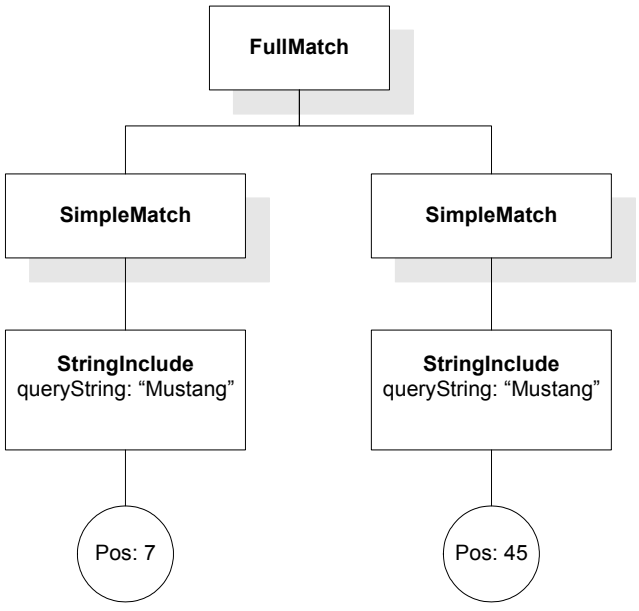


Figure 2 Sample Full Match

Note that a *FullMatch* does not directly list the nodes that satisfy an *FTSelection* – rather, it specifies a position-based "predicate" that nodes need to satisfy in order to qualify as a solution to an *FTSelection*. By specifying a *FullMatch* in terms of positions (a linguistic token notion) rather than nodes, there is

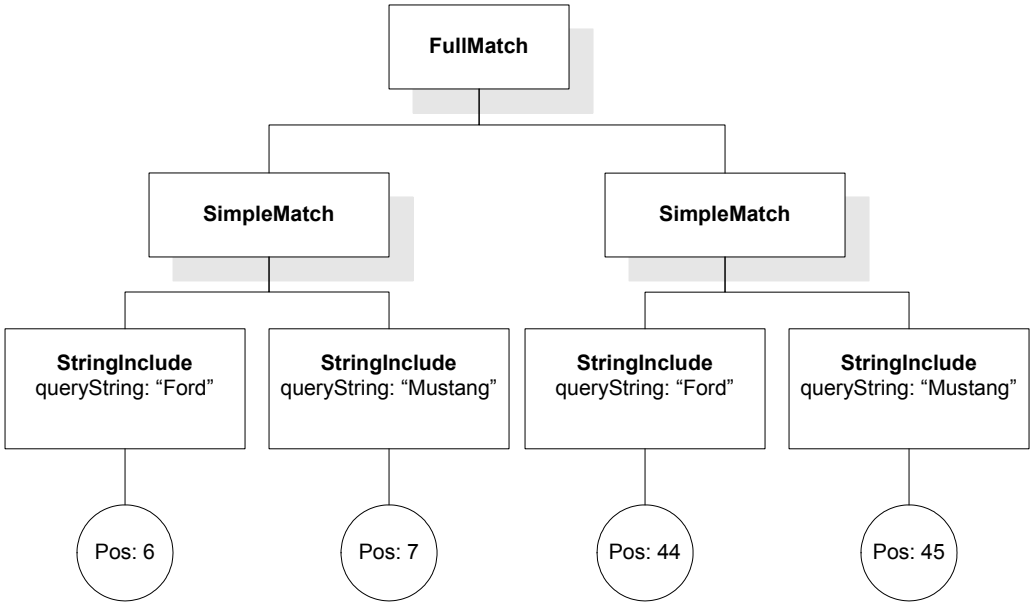


Figure 3 Sample Full Match

sufficient information in a *FullMatch* to achieve full compositionality among *FTSelection*s. At the same time, the interpretation of a *FullMatch* as a predicate on nodes preserves the mapping to the XQuery data model, and allows a *FullMatch* to be mapped back to a sequence of nodes when necessary.

Let us now consider a more complex example. Consider the *FTStringSelection* “Ford Mustang” evaluated over the XML fragment used above. The *FullMatch* for this *FTStringSelection* is shown on Figure 3. There are two possible “solutions” to this *FTStringSelection*, and these are represented by the two *SimpleMatch*es. Each of the *SimpleMatch*es requires *two* linguistic tokens to be matched. The “solution” corresponding to the first *SimpleMatch* is obtained by matching “Ford” at position 6 *and* matching “Mustang” at position 7. Similarly, the “solution” to the second *SimpleMatch* is obtained by matching “Ford” at position 44 *and* “Mustang” at position 45.

The observant reader may have noticed that the *FullMatch* structure resembles the Disjunctive Normal Form (DNF) in propositional and first-order logic. A node is a “solution” to a *FullMatch* iff it is a solution to at least one of its *SimpleMatch*es – this is similar to a DNF formula being satisfied iff at least one of its disjuncts is satisfied. A node is a “solution” to a *SimpleMatch* iff all of its *StringInclude*s are satisfied – this is similar to a disjunct in a DNF formula being true iff all of its atomic terms evaluate to true. The analogy of a *FullMatch* to a DNF formula is a very useful one, and we will use this analogy to help illustrate many of the compositionality properties of *FullMatch* in later sections.

Let us now consider a more sophisticated example of a *FullMatch*. Consider the *FTSelection* `"Mustang" && ! "rust"` that searches for nodes that contain “Mustang” but not “rust”. The *FullMatch* for this *FTSelection* is shown in Figure 4. Observe the new type of component: *StringExclude*. This is the component that corresponds to negation – it specifies that the “solution” to the corresponding simple match should *not* match the linguistic token at the specified position. For instance, the first *SimpleMatch* specifies the “solution” that “Mustang” should be matched at position 7, and “rust” should *not* be matched at position 61.

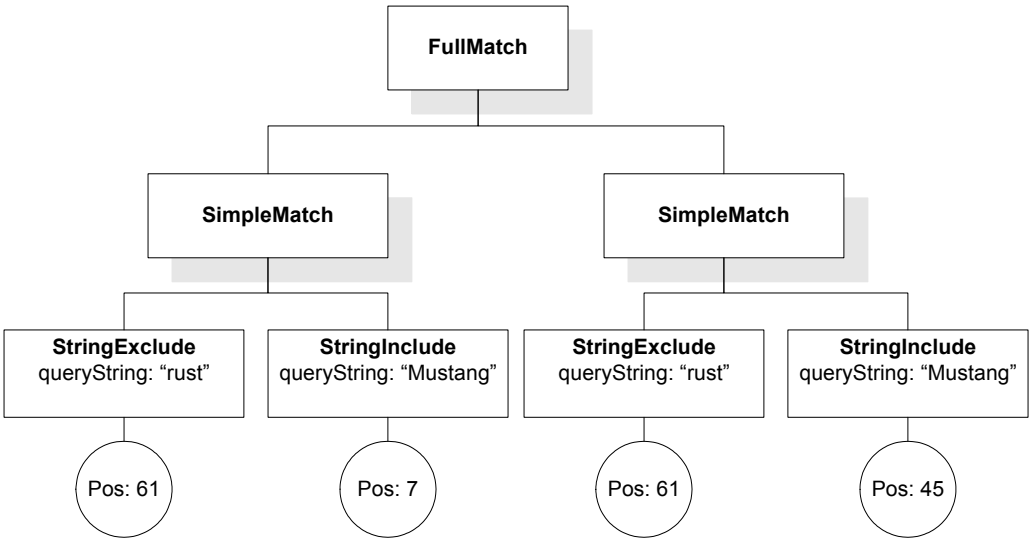


Figure 4 Sample FullMatch

Note that the idea of *StringExclude* also has a direct analogy in a DNF formula – a *StringExclude* corresponds to the negation of an atom in a disjunct.

3.2.2. Formal Model

We are now ready to present the formal model of a *FullMatch*. The UML Static Class diagram of a *FullMatch* is shown in Figure 5. A *FullMatch* contains zero or more *SimpleMatch*es. A *SimpleMatch* contains zero or more *StringInclude*s and zero or more *StringExclude*s. Both *StringInclude* and *StringExclude* are of type *StringMatch*. The *queryString* attribute of specifies the linguistic token associated with *StringMatch*. The *queryPos* attribute specifies the position of the corresponding search token in the query (the need for this field will be apparent in later sections). The *position* attribute is the position where the linguistic token was matched.

Intuitively, a *FullMatch* encodes all possible “solutions” to a *FTSelection*. Each individual solution is encoded in a *SimpleMatch*. The *SimpleMatch* can specify that certain linguistic tokens at specified positions should be included (the *stringInclude* component) and/or specify that certain linguistic tokens at specified positions should not be included (*stringExclude*).

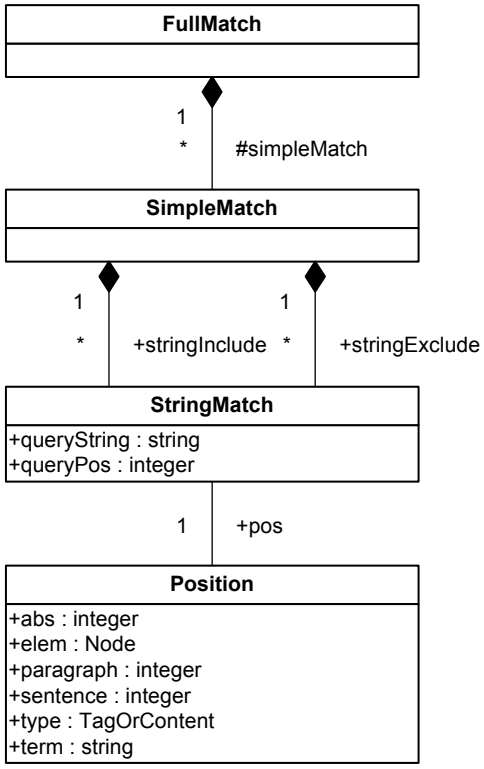


Figure 5 Static Class UML Diagram of the TeXQuery Data Model

3.2.3. XML Representation of a FullMatch

FullMatch has a well-defined hierarchical structure as shown in Figure 5. Therefore, a *FullMatch* can be easily modeled in XML. In subsequent sections, we will use this XML representation to formally describe the semantics of *FTSelection*s. In particular, we will use the XML representation of a *FullMatch* to formally specify how an *FTSelection* operates on zero or more *FullMatch*es to produce a resulting

FullMatch. We will also use the XML representation to specify the formal semantics of the TeXQuery expressions.

A simple XML schema for modeling *FullMatch*es is given below:

```
<xs:complexType name="fts:FullMatch">
   <xs:sequence>
      <xs:element name="simpleMatch"
                  type="fts:SimpleMatch" minOccurrences="1"
                  maxOccurrences="unbounded" />
   </xs:sequence>
</xs:complexType>
<xs:complexType name="fts:SimpleMatch">
   <xs:sequence>
      <xs:element name="stringInclude"
                  type="fts:StringMatch" minOccurrences="0"
                  maxOccurrences="unbounded" />
      <xs:element name="stringExclude"
                  type="fts:StringMatch" minOccurrences="0"
                  maxOccurrences="unbounded" />
   </xs:sequence>
</xs:complexType>
<xs:complexType name="fts:StringMatch">
   <xs:attribute name="queryPos" type="xs:integer" />
   <xs:attribute name="queryString" type="xs:string" />
   <xs:sequence>
      <xs:element name="docPos" type="fts:Position" />
   </xs:sequence>
</xs:complexType>
<xs:complextType name="fts:Position">
   <xs:attribute name="abs" type="xs:integer" />
   <xs:attribute name="para" type="xs:integer" />
   <xs:attribute name="sentence" type="xs:integer" />
   <xs:attribute name="term" type="xs:string" />
   <xs:element name="elem" type="Node" />
</xs:complexType>
```

The *FullMatch* in Figure 4 can be represented as the following XML document conforming the XML schema:

```
<fts:fullMatch>
   <fts:simpleMatch>
```

```
      <fts:stringExclude queryString=”rust” queryPos=”2”>
         <pos @abs=”61” @para=”8” @sentence=”8” term=”rust”>
            <elem id=”...” />
         </pos>
      </fts:stringExclude>
      <fts:stringInclude queryString=”Mustang” queryPos=”1”>
         <pos @abs=”7” @para=”2” @sentence=”2” term=”Mustang”>
            <elem id=”...” />
         </pos>
      </fts:stringInclude>
   </fts:simpleMatch>
   <fts:simpleMatch>
      <fts:stringExclude queryString=”rust” queryPos=”2”>
      </fts:stringExclude>
   </fts:simpleMatch>
      <fts:stringInclude queryString=”Mustang” queryPos=”1”>
         <pos @abs=”45” @para=”8” @sentence=”8” term=”Mustang”>
            <elem id=”...” />
         </pos>
      </fts:stringInclude>
</fts:fullMatch>
```

4. Semantics of TeXQuery Expressions

We now present the formal semantics of TeXQuery expressions. Recall from Part I that there are three TeXQuery expressions: *FTContainsExpr*, *ScoreByExpr*, and *FTSearchExpr*. Each of these expressions takes in (1) an evaluation context consisting of a sequence of nodes (which is the result of a regular XQuery expression), and (2) a *FullMatch* corresponding to an *FTSelection*, and returns a sequence of nodes. Since TeXQuery expressions return results in the XQuery data model (a sequence of nodes), TeXQuery expressions they can be treated like regular XQuery expressions and can be fully composed with other XQuery expressions. In addition, since TeXQuery expressions also map from *FullMatch*es to a sequence of nodes, they provide the "glue" and well-defined semantics for mapping from the *FTSelection* data model and the XQuery data model.

The formal semantics of TeXQuery expressions is specified in terms of two functions. How these two functions are computed is implementation-defined, but the functions have to satisfy some well-defined properties. We first present the properties of the implementation-defined functions, and then present the semantics of TeXQuery expressions based on these functions.

4.1. Implementation-defined functions

The following two functions must be defined by any compliant TeXQuery implementation:

```
function fts:containsPos($node as Node, $pos as fts:Position) as xs:boolean
```

fts:containsPos returns true iff the position *$pos* is contained (directly or indirectly) in node *$node*

```
function fts:score($node as Node,
                   $ftselection as FTSelectionWithScoreWeights)
                  ) as xs:double
```

fts:score returns the score of node *$node* given an *FTSelectionWithScoreWeights*. The exact nature of how the score is computed is implementation-defined and can use score weights in the *FTSelectionWithScoreWeights*. The function, however, should satisfy the following two properties:

1) The score returned should be a floating point number in the range (0, 1], and

2) A higher score should indicate a higher degree of relevance to the *FTSelectionWithScoreWeights*

4.2. Semantics of *FTContainsExpr*

Recall from Part I that an *FTContainsExpr* is of the form "*EvaluationContext* `ftcontains` *FTSelection1*", where *EvaluationContext* is an XQuery expression that returns a sequence of nodes, and *FTSelection1* is an *FTSelection* that returns a *FullMatch*. Intuitively, the *FTContainsExpr* returns true iff some node in the result of *EvaluationContext* satisfies the *FullMatch* returned by *FTSelection1*.

We now formally define the semantics of *FTContainsExpr*. The semantics is defined in terms of a regular XQuery function (without any TeXQuery extensions). The XQuery function takes in two parameters: the first parameter is the sequence of nodes returned by *EvalationContext*, and the second parameter is the XML node representation of the *FullMatch* returned by *FTSelection1* (see Section 3.2.3). The XQuery function (by definition) returns true iff the corresponding *FTContainsExpr* returns true, and thus specifies the semantics of *FTContainsExpr*. Note that by using regular XQuery to specify the formal semantics, we avoid the need to introduce new formalism – we simply reuse the formal semantics of XQuery.

```
define function

FTContainsExpr($evaluationContext as Node*,
```

```
                $fullMatch as element(fullMatch,
                                      fts:FullMatch)
                 ) as xs:Boolean {

   return some $node in $evaluationContext
          satisfies some $simpleMatch in $fullMatch/simpleMatch
                    satisfies satisfiesSimpleMatch($node, $simpleMatch)
}
```

Intuitively, the above function returns true iff some node in the evaluation context satisfies at least one of the SimpleMatches. The function that defines when a node satisfies a *SimpleMatch* (satisfiesSimpleMatch) is defined below.

```
define function
satisfiesSimpleMatch($node as Node,
                     $simpleMatch as element(simpleMatch,
                                             fts:SimpleMatch)
                     ) as xs:Boolean {

 return (every $stringInclude in $simpleMatch/stringInclude
          satisfies fts:containsPos($node, $stringInclude/pos)
         )
         and
         (every $stringExclude in $simpleMatch/stringExclude
          satisfies not fts:containsPos($node, $stringInclude/pos)
          )
}
```

Intuitively, the above function returns true iff the node contains all the *StringInclude* positions, and does not contain all the *StringExclude* positions. Note that fts:containsPos is an implementation-defined function whose semantics is defined in Section 4.1.

4.3. Semantics of *FTScoreExpr*

Recall from Part I that a *FTScoreExpr* is of the form "*EvaluationContext* `ftscore` *FTSelectionWithScoreWeights1*", where *EvaluationContext* is an XQuery expression that returns a sequence of nodes, and *FTSelectionWithScoreWeights1* is an *FTSelectionWithScoreWeights* that returns a *FullMatch* and also specifies score weights. Intuitively, *FTScoreExpr* returns a sequence of scores corresponding to each node in the evaluation context, where each score is computed using the specification in *FTSelectionWithScoreWeights1*. The XQuery function defining this semantics is given below.

```
define function
FTScoreExpr($evaluationContext as Node*,
            $fullMatch as element(fullMatch,
```

```
                                    fts:FullMatch),
            $ftSelection as FTSelectionWithScoreWeights
            ) as xs:double* {

   for $node in $evaluationContext
   return if (FTContainsExpr($node, $fullMatch))
          then fts:score($node, $ftSelection)
          else 0
}
```

For every node in the evaluation context, if the node satisfies the *FullMatch* (checked using FTContainsExpr function defined earlier), then a positive score computed using the implementation-defined function fts:score is returned. Else a zero score is returned.

4.4. Semantics of *FTSearchExpr*

Recall from Part I that an *FTSearchExpr* is of the form "*EvaluationContext* `ftsearch` *FTSelectionWithScoreWeights1*", where *EvaluationContext* is an XQuery expression that returns a sequence of nodes, and *FTSelection1* is an *FTSelection* that returns a *FullMatch*. Intuitively, the *FTSearchExpr* returns the most-specific nodes in the result of *EvaluationContext* or its descendants that satisfy the *FullMatch* returned by *FTSelection1*.

The formal semantics of *FTSearchExpr* is specified by the following XQuery function.

```
define function
FTSearchExpr($evaluationContext as Node*,
             $fullMatch as element(fullMatch,
                                   fts:FullMatch),
            $ftSelection as FTSelectionWithScoreWeights
             ) as Node* {

   for $node in $evaluationContext/descendant-or-self::node()
   where FTContainsExpr($node, $fullMatch)
         and
         every $descendant in $node/descendant::node()
         satisfies not FTContainsExpr($descendant, $fullMatch)
   order by fts:score($node, $ftSelection) descending
   return $node
}
```

The above function first determines all the descendants nodes of the evaluation context (including the evaluation context nodes) in $node. It then returns only those $node nodes that (a) satisfy the *FullMatch*, and (b) do not have any descendants that satisfy the *FullMatch* (checking for *FullMatch* satisfaction is done by a call to the FTContainsExpr function defined earlier). By doing so, the function ensures that only the most specific results for a *FullMatch* are returned – in particular, if a node is returned by

ftsearch, none of its ancestors will be returned. The result nodes are returned sorted in descending order of their score with regards to the *FTSelectionWithScoreWeights* expression.

5. Semantics of *FTSelection*s

In this section, we define the semantics of *FTSelection*s. Recall from Part I and Figure 1 (right arrow) that *FTSelection*s are fully composable, and can be arbitrarily nested under other *FTSelection*s. Also, each *FTSelection* can be associated with context modifiers (such as stemming, stop words, etc.) and score weights. Since score weights are solely interpreted by the implementation-defined scoring function (described in Section 4.1), score weights do not influence the semantics of *FTSelection*s in any way. We will thus not consider score weights when defining the formal semantics.

We now present operational semantics for the evaluation of *FTSelection*s. Specifically, we define a function "evaluate" that takes in three parameters: (1) an *FTSelection*, (2) an evaluation context (specified by the TeXQuery expression the *FTSelection* is nested under), and (3) the default (implementation-defined) set of context modifiers that apply to the evaluation of the *FTSelection*. The "evaluate" function returns the *FullMatch* that is the result of evaluating the *FTSelection*. The "evaluate" function works by recursively calling itself on nested *FTSelection*s, which in turn return *FullMatch*es. Then, the "evaluate" function calls the polymorphic function "applyFTSelection" that implements the evaluation of the particular *FTSelection* applied on the *FullMatch*es returned by the evaluation of the nested *FTSelection*s. Thus full compositionality of *FTSelection*s is achieved as depicted in the right arrow in Figure 1.

We first present a high-level description of the "evaluate" function, and then describe the details.

5.1. "Evaluate" Function: High-Level Description

The high-level pseudo-code (not XQuery function) for the "evaluate" function is given below.

```
function evaluate(ftSelection: FTSelection,
                  evaluationContext: EvaluationContext,
                  modifierContext: Stack)
         returns FullMatch
begin
  switch (ftSelection)

   case (nftSelection: FTSelection    modifier: FTContextModifier):
                        // This is a new context modifier for the
                        // nested FTSelections (nftSelection). So,
                        // create new modifier object and add it to the
                        // top of the current modifier context
                        modifierItem := createModifierItem(modifier);
                        modifierContext.push(modifierItem);
                        resultFullMatch := evaluate(nftSelection,
                                                    evaluationContext,
                                                    modifierContext);
                        modifierContext.pop();
                        return resultFullMatch;
```

```
  case (nftSelection: FTSelection   "weight"   w: FTWeight):
                       // Weight has no bearing on semantics – just
                       // call "evaluate" on nested FTSelection
                       return evaluate(nftSelection,
                                       evaluationContext,
                                       modifierContext);

case (ftSelection: FTStringSelection):
                      //Apply the FTStringSelection in the evaluation
                      //context
                      return applyFTSelection(evaluationContext,
                                              modifierContext,
                                              ftSelection.SearchToken,
                                              ftSelection.queryPos);

 // All FTSelections except FTContextModifier, FTWeight and
 // FTStringSelection
 case (ftSelection: FTAndConnectiv) |
      (ftSelection: FTOrConnective) |
      (ftSelection: FTNegation) |
      (ftSelection: FTMildNegation) |
      (ftSelection: FTOrderSelection) |
      (ftSelection: FTScopeSelection) |
      (ftSelection: FTDistanceSelection) |
      (ftSelection: FTWindowSelection) |
      (ftSelection: FTTimesSelection):
                      // First evaluate nested FTSelections
                      for (each nested FTSelection nftSelection_i) do
                          fullMatch_i := evaluate(nftSelection_i,
                                                  evaluationContext,
                                                  modifierContext);
                      endfor

                      // Now transform nested FullMatches into
                      // result FullMatch. Note that different
                      // types of FTSelections have different
                      // transformations
```

```
                        return applyFTSelection(modifierContext,
                                                ftSelection.Info,
                                                fullMatch1,
                                                ...,
                                                fullMatchn);
  } // end switch
} // end function
```

Let us now walk through the above pseudo-code to understand the semantics of the function. For concreteness, let us assume that the *FTSelection* was invoked inside an ftcontains expression such as "*EvaluationContext* `ftcontains` *FTSelection1*" (of course, the same description carries over to ftsearch and ftscore as well). In order to determine the *FullMatch* result of *FTSelection1*, the "evaluate" function is invoked as follows: evaluate(*FTSelection1*, *EvaluationContext*, *ModifierContext*).

The *ModifierContext* above is the default (implementation-defined) list of modifiers that apply to the evaluation of *FTSelection1* (such as stemming but not thesaurus) and is implementation-defined. Context modifiers embedded in *FTSelection1* can change the modifier context as evaluation proceeds. In order to express the order in which modifiers are applied to an *FTSelection*, the modifiers are organized in a stack. The top modifier in the stack is to be applied first, the next modifier is to be applied second, and so on. The ordering among modifiers is necessary because modifiers are not always commutative – for example, synonym(stem(linguistic token)) is not always the same as stem(synonym(linguistic token)). Of course, modifiers can be reordered when they commute, but this is an optimization issue and is beyond the scope of this semantics document.

Given the invocation of: evaluate(*FTSelection1*, *EvaluationContext*, *ModifierContext*), evaluation proceeds as follows. First, *FTSelection1* is checked to see whether it is a context modifier applied on a nested *FTSelection* (case 1), a weight specification (case 2), a *FTStringSelection* (case 3), or some other *FTSelection* (case 4). Let us consider these three cases in turn.

Case 1: If *FTSelection1* contains a context modifier, then it modifies the context for the nested *FTSelection*. Consequently, a new context modifier element is created and pushed onto the top of the stack of context modifiers. The createModifierElement function used to create a stack element corresponding to the modifier simply creates a data structure that stores the type of modifier (such as stemming, thesaurus, synonyms, ignore, etc.) and the details relating to the modifier (such as the name of the thesaurus, the words to ignore, etc.). The context modifier created is added to the top of the stack because, in the *FTSelection*, it was applied before the other modifiers in the current modifier context. The "evaluate" function is then invoked on the nested *FTSelection* with the new modifier context. When the function returns, the modifier is popped from the stack, and the result of the nested "evaluate" function is returned. The modifier is popped because the modifier context should not apply to *FTSelection*s outside its scope.

Case 2: If *FTSelection1* contains a weight specification, then the specification is simply ignored (because it does not alter semantics). The "evaluate" function is recursively called on the nested *FTSelection* and the resulting *FullMatch* is directly returned.

Case 3: If *FTSelection1* is a *FTStringSelection*, then it does not have any nested *FTSelection*s. Consequently, this is the base of the recursive call, and the *FullMatch* result of the *FTStringSelection* is computed and returned. The *FullMatch* is computed by invoking the applyFTSelection function with the current evaluation context and other necessary information. The semantics of how exactly applyFTSelection creates a *FullMatch* for *FTStringSelection* will be specified in the next section.

Case 4: If *FTSelection1* contains neither a context modifier nor a weight specification and is not a *FTStringSelection*, the *FTSelection* performs some form of full-text operation such as '&&', '||',

'window', etc. Note that these operations are fully-compositional, and can be invoked on nested *FTSelection*s. Consequently, evaluation proceeds as follows. First, the "evaluate" function is recursively invoked on each nested *FTSelection*. The result of evaluating each nested *FTSelection* is a *FullMatch*. These *FullMatch*es are transformed into a result *FullMatch* by applying the full-text operation corresponding to *FTSelection1* (generically called applyFTSelection in the pseudo-code). As an example, let *FTSelection1* be *FTSelection2* && *FTSelection3*. Here *FTSelection2* and *FTSelection3* can themselves be arbitrarily nested *FTSelection*s. Thus, evaluate is invoked on *FTSelection2* and *FTSelection3*, and the resulting *FullMatch*es are transformed to the output *FullMatch* using the applyFTSelection function corresponding to '&&'.

Note that specifying the semantics of the applyFTSelection function for each *FTSelection* is key to specifying the semantics of the *FTSelection* itself. In the subsequent sections, we define the semantics of the applyFTSelection function for each *FTSelection*.

5.2. Semantics of *ApplyFTSelection* Function for each *FTSelection*

We now define the semantics of the ApplyFTSelection function for each *FTSelection*. Recall from the previous section that in the general case, the ApplyFTSelection function takes in (a) the current evaluation context, (b) the current list of modifiers, (c) other information specific to each *FTSelection*, and (d) the *FullMatch* results of nested *FTSelection*s. Not all input parameters are used in every ApplyFTSelection function corresponding to an *FTSelection*, and for ease of exposition, we drop the irrelevant parameters when specifying the semantics of ApplyFTSelection for each *FTSelection*. The ApplyFTSelection function always returns a *FullMatch* for every *FTSelection*.

We use an XQuery function to specify the semantics of each ApplyFTSelection. This is possible because the inputs and output of the function can be specified in XML. Specifically, the evaluation context is already represented as a sequence of XQuery nodes. The list of modifiers can be represented as a sequence of modifier XML elements. A *FullMatch* can be represented in XML form as described in Section 3.2.3.

The formal semantics of the ApplyFTSelection function for each *FTSelection* is specified in terms of four functions. How these four functions are computed is implementation-defined, but the functions have to satisfy some well-defined properties. We first present the properties of the implementation-defined functions, and then present the semantics of ApplyFTSelection in terms of these functions.

5.2.1. Implementation-defined functions

The following four functions must be defined by any compliant TeXQuery implementation:

```
function fts:matchStr($evaluationContext as Node*,
                      $modifierContext as fts:ModifierContext,
                      $searchToken as xs:string
                      ) as fts:Position*
```

The above function returns all the positions in nodes in *$evaluationContext* that match the search token *$searchToken* when using the modifiers in *$modifierContext*. The modifiers that occur at the beginning of the list should be applied before modifiers that occur later in the list.

```
function fts:posDistance($modifierContext as fts:ModifierContext,
                         $pos1 as fts:Position,
                         $pos2 as fts:Position
                         ) as xs:integer
```

The above function returns the number of linguistic tokens that occur in positions between the positions *$pos1* and *$pos2*. For example, two consecutive positions have a distance of 0. If *$pos1*

and *$pos2* are the same, then the distance is also defined to be 0. The *$modifierContext* may specify linguistic tokens that must be ignored in computing this distance (e.g., stop words, special characters in "`without special characters`" context, terms from ignored tags or element content).

```
function fts:paraDistance($modCtx as fts:ModifierContext,
                          $p1 as fts:Position,
                          $p2 as fts:Position
                          ) as xs:integer
```

The above function returns the number of paragraphs that occur between the positions *$pos1* and *$pos2*. The *$modifierContext* may specify linguistic tokens that must be ignored in computing this distance; specifically, paragraphs consisting entirely of ignored linguistic tokens are not counted when computing the distance.

```
function fts:sentenceDistance($modCtx as fts:ModifierContext,
                              $p1 as fts:Position,
                              $p2 as fts:Position
                              ) as xs:integer
```

The above function returns the number of sentences that occur between the positions *$pos1* and *$pos2*. The *$modifierContext* may specify linguistic tokens that must be ignored in computing this distance; specifically, paragraphs consisting entirely of ignored linguistic tokens are not counted when computing the distance.

We now specify the semantics of each ApplyFTSelection function in terms of the above functions.

5.2.2. Semantics of *FTStringSelection*

We only consider the case where *FTStringSelection* is a single search token. The other cases can be rewritten as complex *FTSelection*s that operate on single string *FTStringSelection*s, as described in Part I.

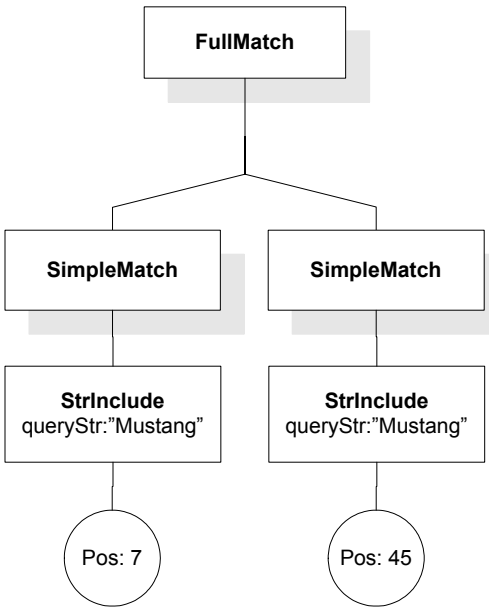
The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, the search token, and the position where the search token occurs in the query. Since *FTStringSelection* does not have nested *FTSelection*s, the ApplyFTSelection does not take in any *FullMatch* parameters corresponding to nested *FTSelection* results. The function definition is given below.

```
define function fts:ApplyFTSelection(
            $evaluationContext as Node*,
            $modifierContext as fts:ModifierContext,
            $searchToken as xs:string,
            $queryPos as xs:integer)
            as element(fullMatch, fts:FullMatch) {


  <fullMatch>
    {let $token_pos := fts:matchStr($evaluationContext,
                                    $modifierContext,
                                    $searchToken)
     for $pos in $token_pos
     return
```

```
        <simpleMatch>
          <stringInclude queryPos="{$queryPos}" q ueryString="{$string}" >
            {$pos}
          </stringInclude>
        </simpleMatch>}
   </fullMatch>
}
```

Intuitively, the *FullMatch* corresponding to an *FTStringSelection* corresponds to a set of *SimpleMatch*es, each of which is associated with a position where the corresponding search token was found. For example, the *FullMatch* result for the *FTStringSelection* "Mustang" evaluated in the context of the sample document from Section 3 will be (in graphical terms):



5.2.3. FTOrConnective

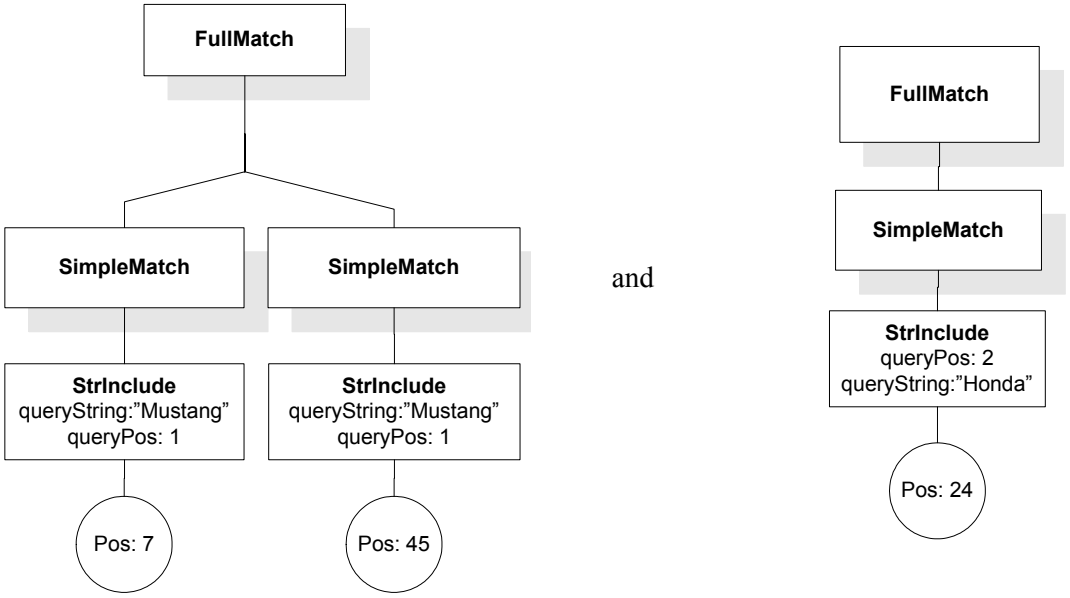
The parameters of the ApplyFTSelection function are the two *FullMatch* parameters corresponding to the results of the two nested *FTSelections*. The evaluation context and the modifier context are not used in this case. The function definition is given below.

```
define function fts:ApplyFTSelection (
         $fullMatch1 as element(fullMatch, fts:FullMatch),
         $fullMatch2 as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      ($fullMatch1/simpleMatch
       $fullMatch2/simpleMatch)
   </fullMatch>
```

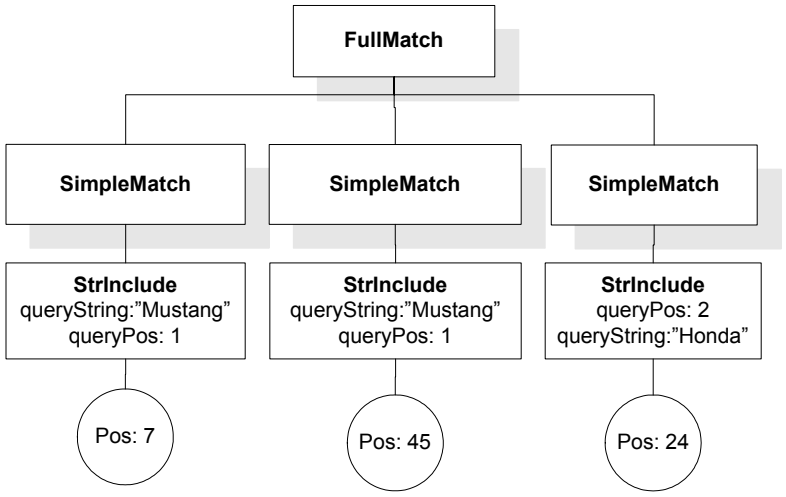
```
}
```

The function creates a new *FullMatch* whose *SimpleMatch*es are simply the union of those found in the input *FullMatch*es. The rationale for this semantics is that each *SimpleMatch* represents one possible "solution" to the corresponding *FTSelection*. Thus, if we "or" two *FullMatch*es, a *SimpleMatch* from either of the *FullMatch*es should also be a solution.

As an example, consider the *FTSelection* `"Mustang" || "Honda"` in the context of the sample document in Section 3. The *FullMatch*es corresponding to "Mustang" and "Honda" are:



The *FullMatch* produced by ApplyFTSelection for FTOrConnective is:



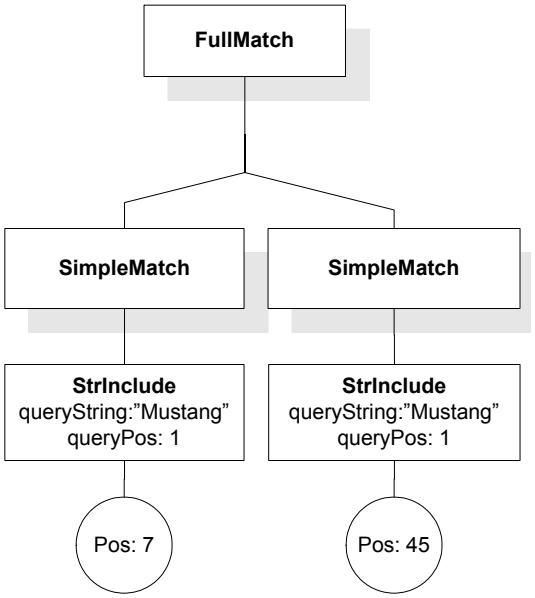
5.2.4. FTAndConnective

The parameters of the ApplyFTSelection function are the two *FullMatch* parameters corresponding to the results of the two nested *FTSelections*. The evaluation context and the modifier context are not used in this case. The function definition is given below.

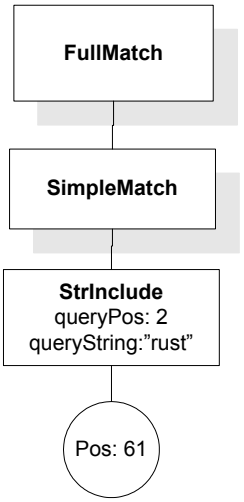
```
define function fts:ApplyFTSelection (
         $fullMatch1 as element(fullMatch, fts:FullMatch),
         $fullMatch2 as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm1 in $fullMatch1/simpleMatch
       for $sm2 in $fullMatch2/simpleMatch
       return
         <simpleMatch>
            {$sm1/*
             $sm2/*}
         <simpleMatch>
   </fullMatch>
}
```

Intuitively, the result of a conjunction is a new *FullMatch* that contains the "Cartesian product" of the simple matches of the participating *FTSelection*s. Every resulting simple match is formed the combination of the *stringInclude* components and *stringExclude* components from each of the *FullMatch*es of the nested *FTSelection* conditions. Thus every simple match will contain the positions to satisfy a *SimpleMatch* from both original *FTSelection*s and will exclude the positions that will violate the same *SimpleMatch*es.

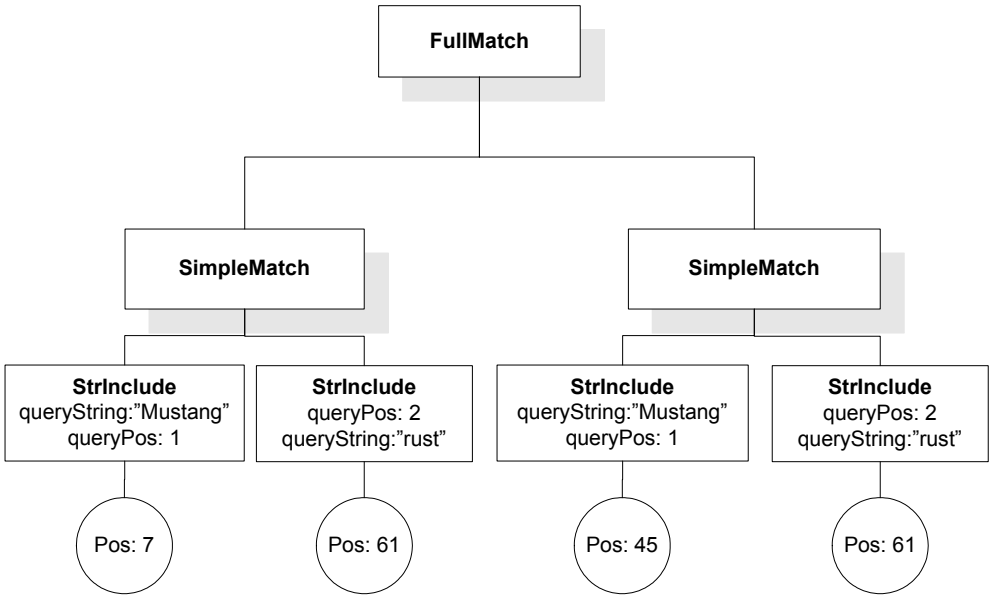
As an example let us consider the *FTSelection* `"Mustang" && "rust"` in the context of the sample document in 3. The source *FullMatch*es are:



and



The *FTAndConnective* converts them to*:*



5.2.5. FTNegation

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, and one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s to be negated. The evaluation context and the modifier context are not used in this case. The function definition is given below.

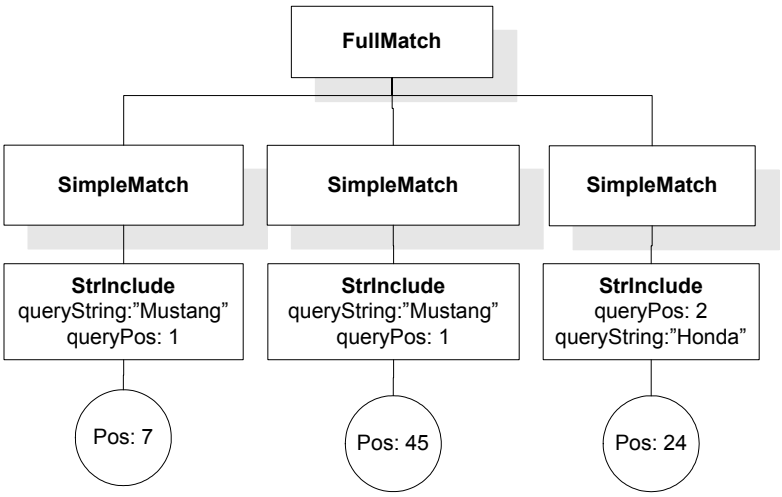
```
define function fts:InvertStringMatch($strm) {
   if ($strm instanceof element(stringExclude)) then
```

```
      <stringInclude queryPos="{$strm/@queryPos}"
                  queryString="{$strm/@queryString}">
         {$strm/docPos}
      </stringInclude>
   else
      <stringExclude queryPos="{$strm/@queryPos}"
                  queryString="{$strm/@queryString}">
         {$strm/docPos}
      </stringInclude>
}
define function fts:NegationHelper($sms) {
   <fullMatch>
      {for $sm in $sms/simpleMatch[1]/child::element()
       for $rest in
            fts:negt_helper(fn:subsequence($sms/simpleMatch, 2)
            /simpleMatch
       return
            <simpleMatch>
               (fts:InvertStringMatch($sm)
                $rest/*)
            </simpleMatch>
      }
   </fullMatch>
}
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   {fts:NegationHelper($fullMatch)}
}
```

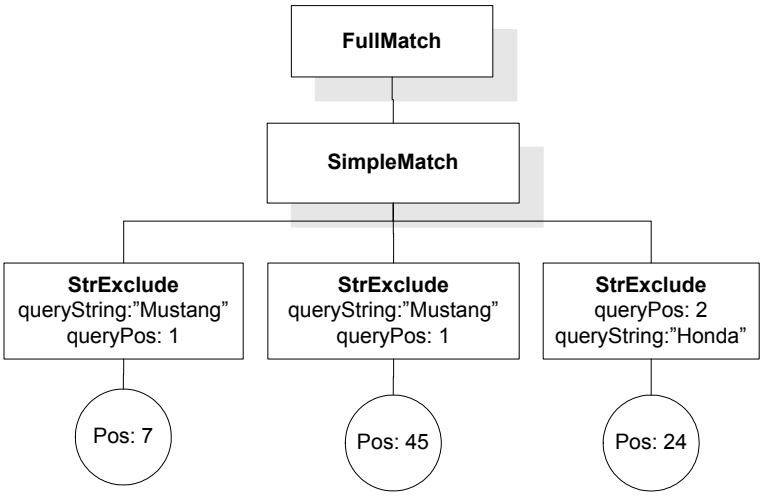
The process of the generation of the resulting full match of an *FTNegation* resembles the transformation of a negation of prepositional formula in DNF back to DNF. The intuition is that negation of a *FullMatch* requires the inversion of all the conditions on the nodes encoded by the *FullMatch*.

In the implementation above, this inversion is implemented as follows. The function fts:invertStringMatch inverts a *stringInclude* into a *stringExclude* and vice versa. The function fts:neg_helper transforms the source *SimpleMatch*es into the resulting *SimpleMatch*es by combining a the inversions of a *stringInlcude* or *stringExclude* component from every source *SimpleMatch* into a new *SimpleMatch*.

As an example, let us consider the *FTSelection* ! (`"Mustang" || "Honda"`) in the context of the sample document in 3. The source *FullMatch* is:



The *FTNegation* will transform it to:



5.2.6. FTMildNegation

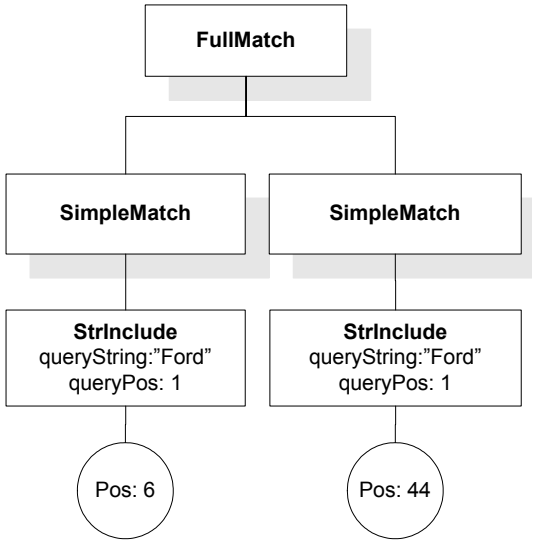
The parameters of the ApplyFTSelection function are the two *FullMatch* parameters corresponding to the results of the two nested *FTSelections*. The evaluation context and the modifier context are not used in this case. The function definition is given below.

```
define function fts:ApplyFTSelection (
         $fullMatch1 as element(fullMatch, fts:FullMatch),
         $fullMatch2 as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {let $pos2=$fullMatch2/simpleMatch/stringInclude/docPos
       return
         $fullMatch1/simpleMatch[./stringInclude/docPos != $pos2]
```

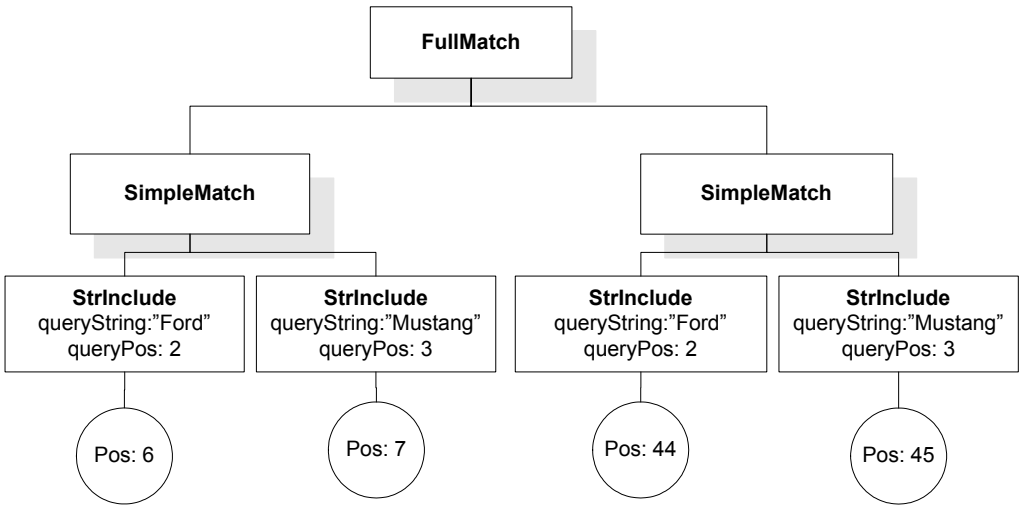
```
        }
    </fullMatch>
}
```

The resulting *FullMAtch* consists of those *SimpleMatch*es of the first operand that do not mention in their *stringInclude* components positions mentioned in a *stringInclude* component in the *FullMatch* of the second operand.

As an example, consider the *FTSelection* (`"Ford" ignore "Ford Mustang"`) in the context of the sample document in 3. The source *FullMatch*es are:



and



The *FTMildNegation* transform these to an empty *FullMatch* because both position 6 and position 44 from the first *FullMatch* contain only positions from *stringInclude* components of the second *FullMatch*.

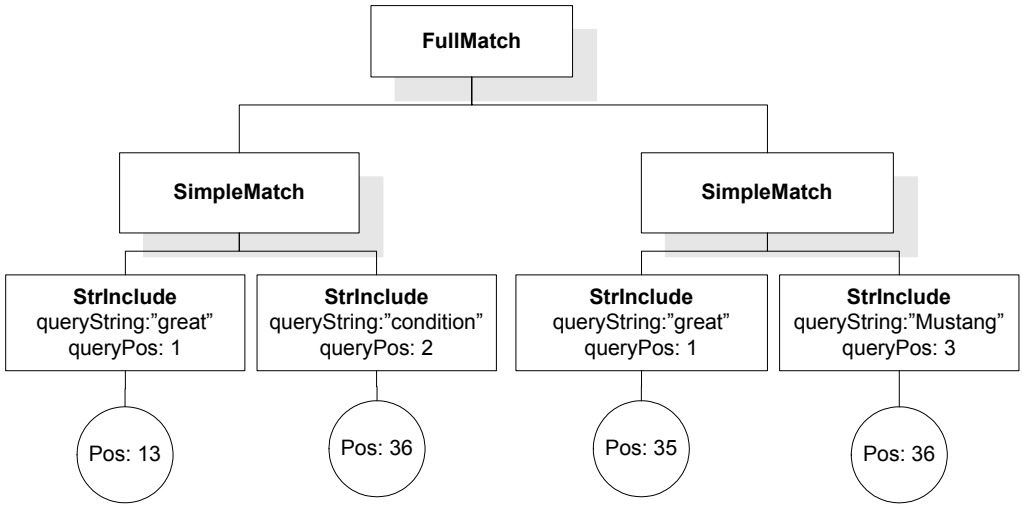
5.2.7. FTOrderSelection

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, and one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s. The evaluation context and the modifier context are not used in this case. The function definition is given below.

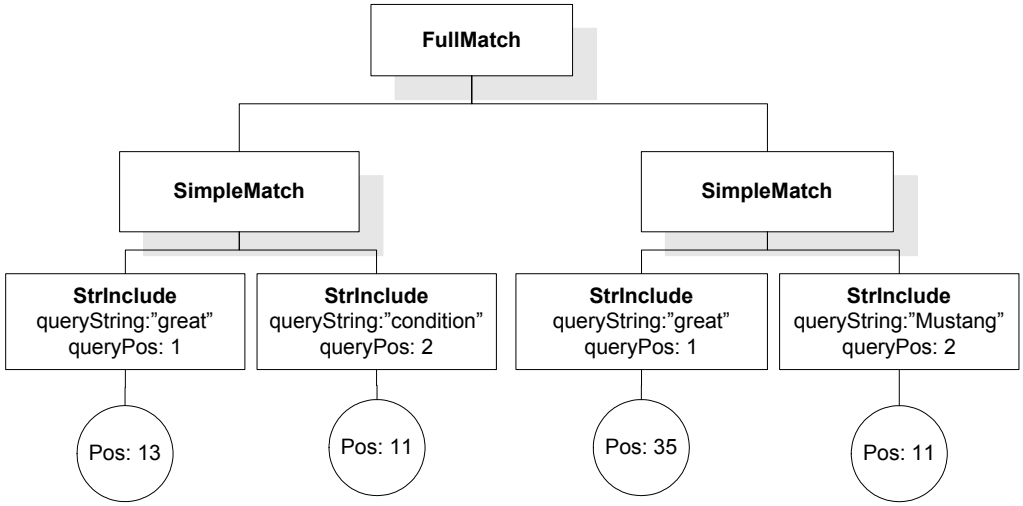
```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[
                        every $si1 in ./stringInclude,
                              $si2 in ./stringInclude
                        satisfies
                             ($si1/docPos/@abs<=$si2/docPos/@abs and
                              $si1/@queryPos<=$si2/@queryPos)
                         or
                             ($si1/docPos/@abs>=$si2/docPos/@abs and
                              $si1/@queryPos>=$si2/@queryPos)
                         ]
      }
   </fullMatch>
}
```

The resulting *FullMatch* contains all *SimpleMatch*es of the parameter whose positions in the *stringInclude* elements are in the order of the query positions of their query strings.

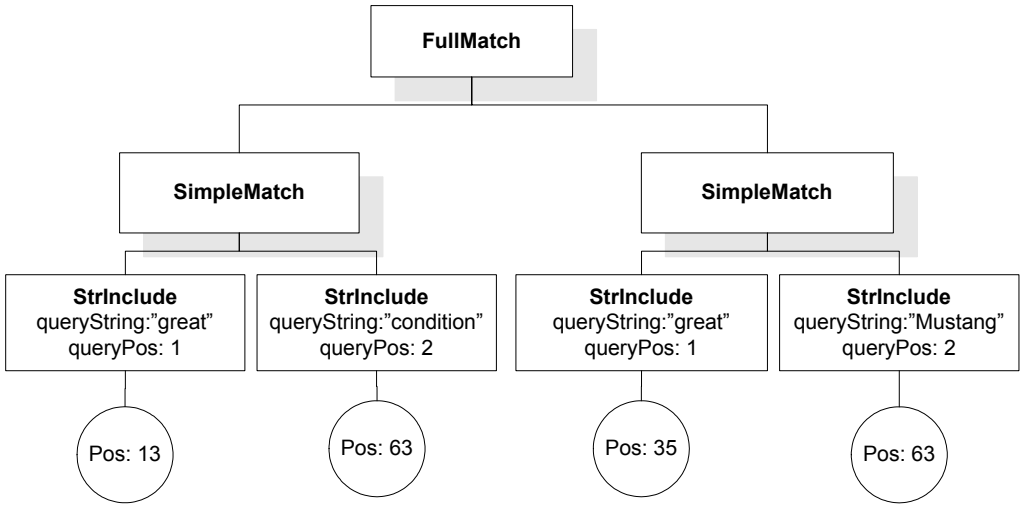
As an example, consider the *FTSelection* (`"great" && "condition") in this order` in the context of the sample document in 3. The source *FullMatch* is:



Continues on next diagram



Continues on next diagram



The *FTOrderSelection* will return only the second and the third part. The positions of terms in the first part are in reverse order to the query terms as determined by *queryPos*.

5.2.8. FTScopeSelection

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, and one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s. The evaluation context and the modifier context are not used in this case. The functions definitions depending on the type of the scope (node, paragraph, sentence) and the scope predicate (same, different) are given below.

In the case of a scope "`same node`", the semantics is given by the XQuery function:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[
            every $si in ./stringInclude
            satisfies $si/pos/elem = ./stringInclude[1]/pos/elem]
      }
   </fullMatch>
}
```

The semantic for the scope "`different node`" is given by the function:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[
                        every $si1 in ./stringInclude,
```

```
                              $si2 in ./stringInclude
                        satisfies $si1=$si2
                                  or
                                  $si1/pos/elem!= $si2/pos/elem]
      }
   </fullMatch>
}
```

The semantics for the case of sentence or paragraph scope is analogous. In case of "`same sentence`", the semantics is given by:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[every $si in ./stringInclude
                              satisfies $si/pos/@sentence =
                                      ./stringInclude[1]/pos/@sentence]
      }
   </fullMatch>
}
```

Similarly, the semantics for "`different sentence`" is given by:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[
              every $si1 in ./stringInclude,
                    $si2 in ./stringInclude
              satisfies $si1=$si2
                        or
                        $si1/pos/@sentence != $si2/pos/@sentence
                       ]
      }
   </fullMatch>
}
```

In case of "`same paragraph`", the semantics is given by:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
```

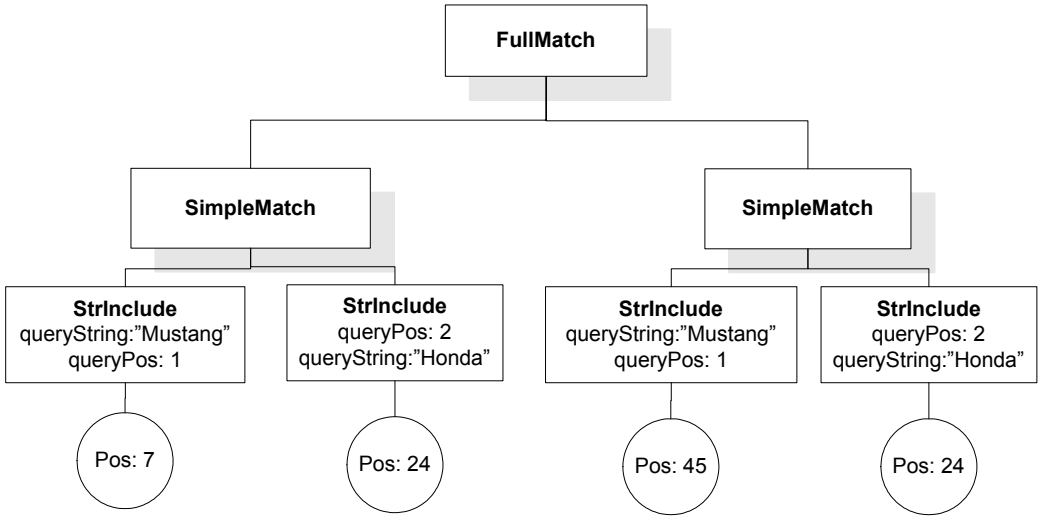
```
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[every $si in ./stringInclude
                              satisfies $si/pos/@para =
                                        ./stringInclude[1]/pos/@para]
      }
   </fullMatch>
}
```

Finally, the semantics for "`different paragraph`" is given by:

```
define function fts:ApplyFTSelection (
         $fullMatch as element(fullMatch, fts:FullMatch))
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {$fullMatch/simpleMatch[
                       every $si1 in ./stringInclude,
                             $si2 in ./stringInclude
                       satisfies $si1=$si2
                                 or
                                 $si1/pos/@para != $si2/pos/@para
                      ]
      }
   </fullMatch>
}
```

If for instance the type of the scope is "node", the semantics is straightforward. For every *SimpleMatch* from the *FullMatch* of the operand, it filters those that contain string matches from *stringInclude* only in the same (different) element node. The cases for scope type paragraph or sentence are analogous.

As an example, consider the *FTSelection* (`"Mustang" && "Honda") same node` in the context of the sample document in 3. The source *FullMatch* is:



The *FTScopeSelection* will convert this to an empty *FullMatch* because neither *SimpleMatches* contain positions from a single element.

5.2.9. FTDistanceSelection

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s, and one or two integers depending on the range specified *FTRangeSpec* used. The evaluation context is not used in this case, but the modifier context is needed because some of the linguistic tokens may need to be ignored (e.g. because they occur in the stop-words list) and therefore must not be counted against the distance. The semantics for the different cases depending on the distance units (words – linguistic tokens, paragraphs, sentences) and the *FTRangeSpec* used are given below.

The function for the case "`word distance exactly N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/@abs ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:posDistance($SMCtx,
                           $sorted[$index]/docPos,
```

```
                              $sorted[$index + 1]/docPos) = $n
       return $sm
      }
   </fullMatch>
}
```

Similarly, the semantics for the case of "`word distance at least N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/@abs ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:posDistance($SMCtx,
                              $sorted[$index]/docPos,
                              $sorted[$index + 1]/docPos) >= $n
       return $sm
      }
   </fullMatch>
}
```

The semantics for the case of "`word distance at most N`" is given by:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/@abs ascending
```

```
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:posDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) <= $n
       return $sm
      }
   </fullMatch>
}
```

The semantics for the final case of "`word distance from M to N`" is given by:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $m as xs:integer,
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/@abs ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               let $dist = fts:posDistance(
                                   $SMCtx,
                                   $sorted[$index]/docPos,
                                   $sorted[$index + 1]/docPos)
               return $m <= $dist and $dist <= $n
       return $sm
      }
   </fullMatch>
}
```

The function for the case "`sentence distance exactly N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
```

```
        $fullMatch as element(fullMatch, fts:FullMatch))
        $n as xs:integer)
        as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/sentence ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:sentenceDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) = $n
       return $sm
      }
   </fullMatch>
}
```

Similarly, the semantics for the case of "`sentence distance at least N`" is presented below:

```
define function fts:ApplyFTSelection (
        $modCtx as fts:ModifierCtx,
        $fullMatch as element(fullMatch, fts:FullMatch))
        $n as xs:integer)
        as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/sentence ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:sentenceDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) >= $n
       return $sm
      }
```

```
   </fullMatch>
}
```

The semantics for the case of "`sentence distance at most N`" is given by:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/sentence ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:sentenceDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) <= $n
       return $sm
      }
   </fullMatch>
}
```

The semantics for the final case of "`sentence distance from M to N`" is given by:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $m as xs:integer,
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/sentence ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
```

```
              satisfies
                let $dist = fts:sentenceDistance(
                                        $SMCtx,
                                        $sorted[$index]/docPos,
                                        $sorted[$index + 1]/docPos)
                return $m <= $dist and $dist <= $n
        return $sm
       }
   </fullMatch>
}
```

The function for the case "`paragraph distance exactly N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/para ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:paraDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) = $n
       return $sm
      }
   </fullMatch>
}
```

Similarly, the semantics for the case of "`paragraph distance at least N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
```

```
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/para ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:paraDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) >= $n
       return $sm
      }
   </fullMatch>
}
```

The semantics for the case of "`paragraph distance at most N`" is given by:

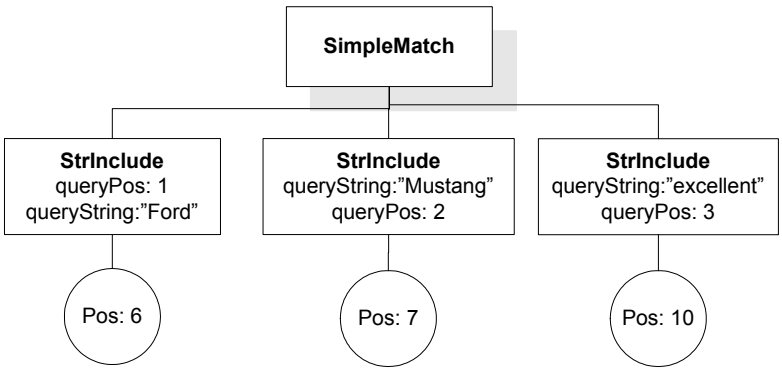
```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/para ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               fts:paraDistance($SMCtx,
                           $sorted[$index]/docPos,
                           $sorted[$index + 1]/docPos) <= $n
       return $sm
      }
   </fullMatch>
}
```

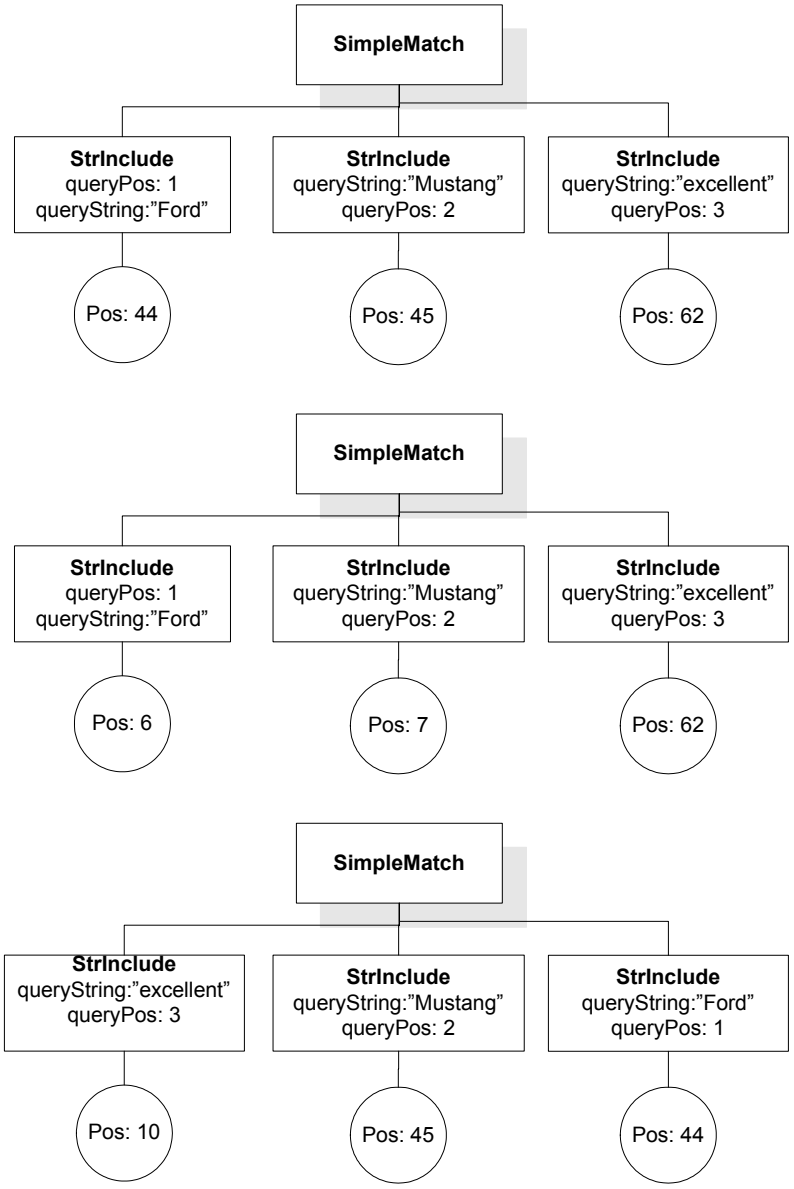
The semantics for the final case of "`paragraph distance from M to N`" is given by:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $m as xs:integer,
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $sorted=
            for $si in ./stringInclude[isValidPos($SMCtx, ./pos)]
            order by $si/docPos/para ascending
            return $si
       where every $index in (1 to fn:count($sorted)-1)
             satisfies
               let $dist = fts:paraDistance(
                                   $SMCtx,
                                   $sorted[$index]/docPos,
                                   $sorted[$index + 1]/docPos)
               return $m <= $dist and $dist <= $n
       return $sm
      }
   </fullMatch>
}
```

Intuitively, the resulting *FullMatch* contains those *SimpleMatch*es of the operand that satisfy the condition that the distance (measured in words/linguistic tokens, sentences, orparagraphs) for every couple of consecutive valid positions in *stringInclude* elements is in the specified interval. Here by consecutive, we mean with no other valid positions from the same *stringInclude* element between them.

As an example, consider the *FTDistanceSelection* `("Ford Mustant" && "excellent") word distance at most 3` over the sample document fragment in 3. The four simple matches of the source full match for `("Ford Mustant" && "excellent")` are given below:





The result for the above *FTDistanceSelection* will consist of only the first simple match because only their the distance between consecutive positions (0 and 2 in this case) are less or equal to 3.

5.2.10. FTWindowSelection

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s, and one or two integers depending on the range specified *FTRangeSpec* used. The evaluation context is not used in this case, but the modifier context is needed because some of the linguistic tokens may need to be ignored (e.g. because they occur in the stop-words list) and therefore must not be counted against the window size. The semantics for the different cases depending on the range specification *FTRangeSpec* used follow.

The function for the case "`window exactly N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
```

```
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $pos := $sm/docPos[isValidPos($SMCtx, .)]
       let $max_pos = fn:max($pos/@abs)
       let $min_pos = fn:min($pos/@abs)
       let $window := fts:posDistance($min_pos, $max_pos) + 2
       where $window = $n
       return $sm
      }
   </fullMatch>
}
```

The function for the case "`window at least N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $pos := $sm/docPos[isValidPos($SMCtx, .)]
       let $max_pos = fn:max($pos/@abs)
       let $min_pos = fn:min($pos/@abs)
       let $window := fts:posDistance($min_pos, $max_pos) + 2
       where $window >= $n
       return $sm
      }
   </fullMatch>
}
```

The function for the case "`window at least N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
```

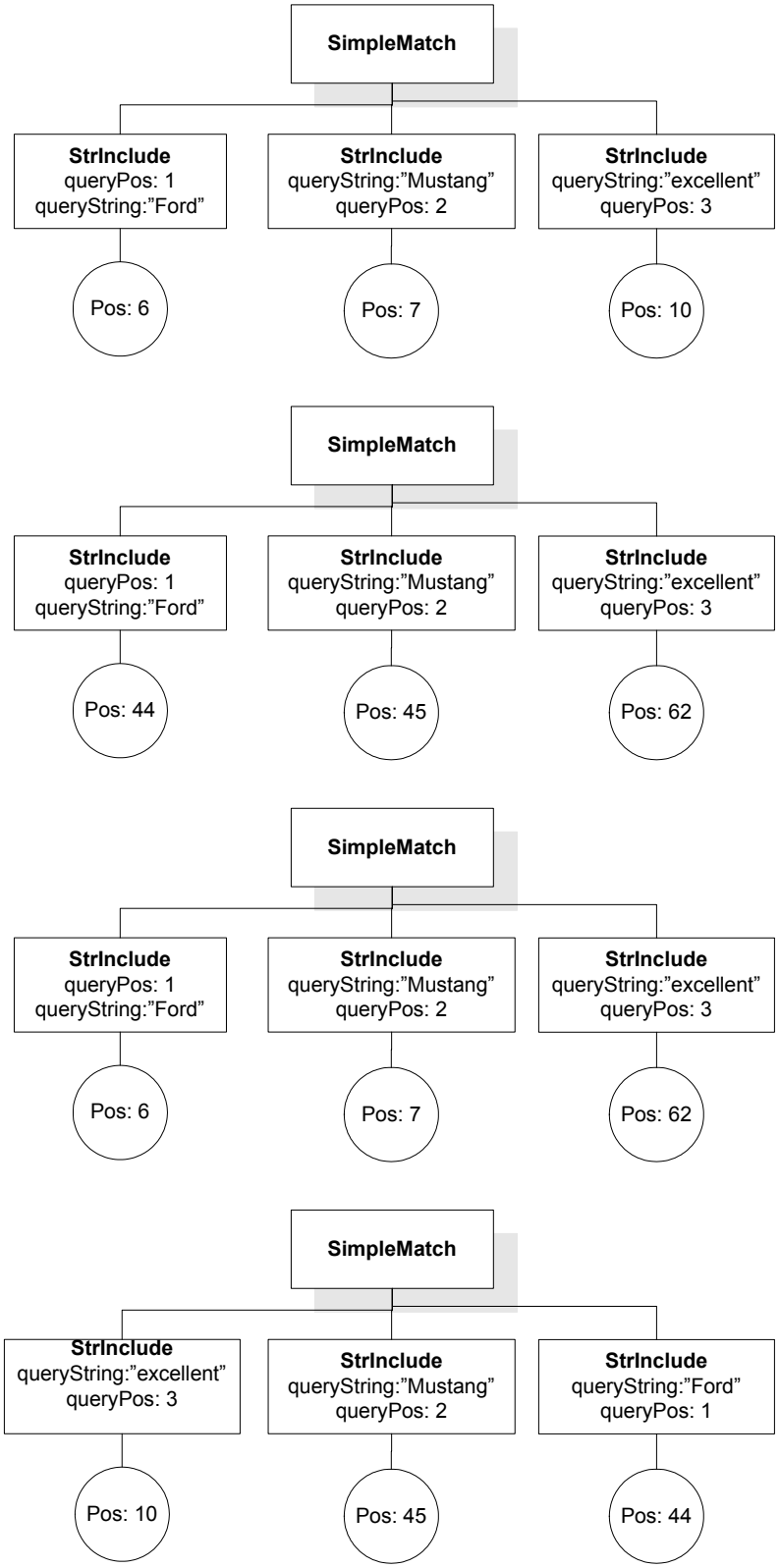
```
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $pos := $sm/docPos[isValidPos($SMCtx, .)]
       let $max_pos = fn:max($pos/@abs)
       let $min_pos = fn:min($pos/@abs)
       let $window := fts:posDistance($min_pos, $max_pos) + 2
       where $window <= $n
       return $sm
      }
   </fullMatch>
}
```

The function for the case "`window from M to N`" is presented below:

```
define function fts:ApplyFTSelection (
         $modCtx as fts:ModifierCtx,
         $fullMatch as element(fullMatch, fts:FullMatch))
         $n as xs:integer)
         as element(fullMatch, fts:FullMatch){
   <fullMatch>
      {for $sm in $fullMatch/simpleMatch
       let $pos := $sm/docPos[isValidPos($SMCtx, .)]
       let $max_pos = fn:max($pos/@abs)
       let $min_pos = fn:min($pos/@abs)
       let $window := fts:posDistance($min_pos, $max_pos) + 2
       where $m <= $windows and $window <= $n
       return $sm
      }
   </fullMatch>
}
```

Intuitively, the resulting *FullMatch* contains those *SimpleMatch*es of the operand that satisfy the condition that the distance between the maximum position and the minimum position plus two (because the include both positions) is within the specified interval.

As an example, consider the *FTWindowSelection* `("Ford Mustant" && "excellent") word distance at most 20` over the sample document fragment in 3. The four simple matches of the source full match for `("Ford Mustant" && "excellent")` are given below:



The result for the above *FTWindowSelection* will consist of the first two simple matches because their window sizes are 5 and 19 respectively.

5.2.11. FTTimesSelection

The parameters of the ApplyFTSelection function are the evaluation context, the list of context modifiers, one *FullMatch* parameter corresponding to the result of the nested *FTSelection*s, and one or two integers depending on the range specified *FTRangeSpec* used. The evaluation context and the modifier context are not used in this case.

The function definitions, depending the range specification *FTRangeSpec* limiting the number of occurrences, follow.

```
define function fts:FormCombinations($sms, $times) {
   if (fn:count($sms) eq 0) then ()
   else  if ($times eq 0) then ()
   else {
      fts:formCombination(fn:subsequence($sms, 2), $times)
      (<simpleMatch>
         $sms[1]
         fts:formCombinations(fn:subsequence($sms, 2),$times-1)/*
       </simpleMatch>
      )
   }
}
define function fts::FormRange($sms, $l, $u) {
   let $lower_match :=
      <fullMatch>
         {fts:formCombinations($sms, $l) }
      </fullMatch>
   return
      if ($l > $u) then ()
      else fts:applyAndConnective(
               <fullMatch>
                  {fts:FormCombinations($sms, $l)}
               </fullMatch>,
               fts::applyNegation(
                  <fullMatch>
                     {fts:FormCombinations($sms, $u+1)}
                  </fullMatch>)
            )
}
```

We now define the semantics for the case "`exactly N` occurrences":

```
define function fts:ApplyFTSelection (
```

```
          $fullMatch as element(fullMatch, fts:FullMatch))
          $n as xs:integer)
          as element(fullMatch, fts:FullMatch){
   fts:formRange($fullMatch/simpleMatch, $n, $n)
}
```

We next define the semantics for the case "`at least N` occurrences":

```
define function fts:ApplyFTSelection (
          $fullMatch as element(fullMatch, fts:FullMatch))
          $n as xs:integer)
          as element(fullMatch, fts:FullMatch){
   fts:formCombinations($fullMatch/simpleMatch, $n)
}
```

We next define the semantics for the case "`at most N` occurrences":

```
define function fts:ApplyFTSelection (
          $fullMatch as element(fullMatch, fts:FullMatch))
          $n as xs:integer)
          as element(fullMatch, fts:FullMatch){
   fts:formRange($fullMatch/simpleMatch, 0, $n)
}
```

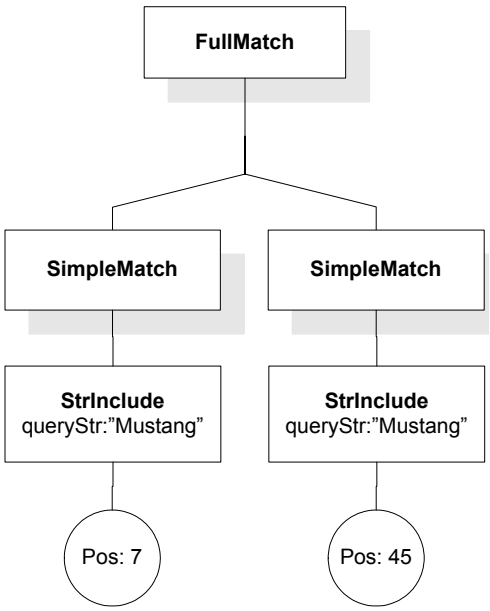
Finally, we define the semantics for the case "`from M to N` occurrences":

```
define function fts:ApplyFTSelection (
          $fullMatch as element(fullMatch, fts:FullMatch))
          $m as xs:integer,
          $n as xs:integer)
          as element(fullMatch, fts:FullMatch){
   fts:formRange($fullMatch/simpleMatch, $m, $n)
}
```

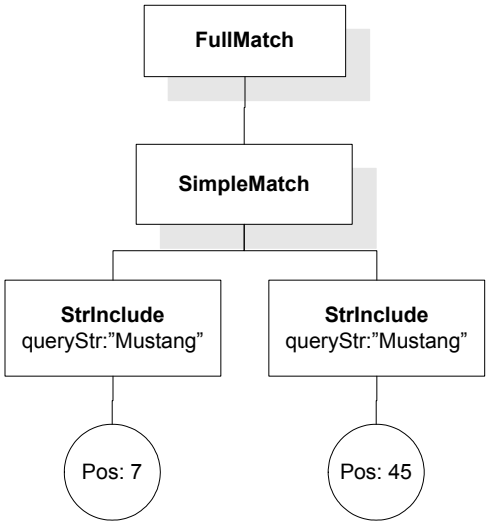
The intuition is as follows. The way to ensure that there are at least *N* different matches of an *FTSelection* is to ensure that at least *N* of its *SimpleMatch*es occur simultaneously. This is similar to forming their conjunction: combine *N* distinct simple matches into one simple match. Therefore, the full match for the selection condition involving the range specifier "`at least N`" is to form all possible combinations of *N* simple matches of the operand and form one simple match for each combination negating the rest of the simple matches. This operations is performed in the function fts:FormCombinations.

In the case of another range [*l*, *u*], it is treated as the condition "at least *l* and not at least *u*+1". This transformation is performed in the function fts:FormRange.

As an example, consider the *FTTimesSelection* `"Mustang" at least 2 occurrences` over the sample document fragment in 3. The source full match of the *FTStringSelection* `"Mustang"` is:



The result will consist of all couples of simple matches from above:



6. Example

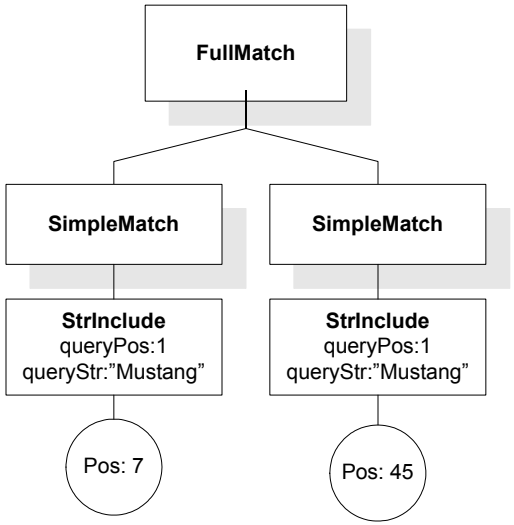
We will now show the evaluation of a more elaborate example of *FTSelection*. We use the same sample document as in Section 3. For convenience, we present it again here.

```
<offer(1) id(2)="1000(3)" price(4)="10000(5)">
   Ford(6) Mustang(7) 2000(8), 65K(9), excellent(10)
condition(11), runs(12) great(13), AC(14), CC(15),
power(16) all(17)
</offer(18)>
<offer(19) id(20)="1001(21)" price(22)="8000(23)">
   Honda(24) Accord(25) 1999(26), 78K(27), A(28)/C(29),
cruise(30) control(31), runs(32) and(33) looks(34)
great(35), excellent(36) condition(37)
</offer(38)>
<offer(39) id(40)="1005(41)" price(42)="5500(43)">
   Ford(44) Mustang(45), 1995(46), 150K(47) highway(48)
mileage(50), little(60) rust(61), excellent(62)
condition(63)
</offer(64)>
```

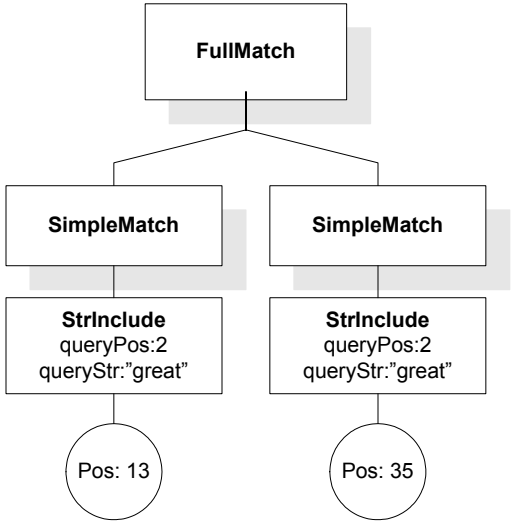
We will walk through the evaluation of the following *FTSelection*:

```
(
   (“mustang” &&
      ((“great” || “excellent”) at least 2 occurrences)
   ) window at most 30
   &&
   ! “rust”
) same node
```

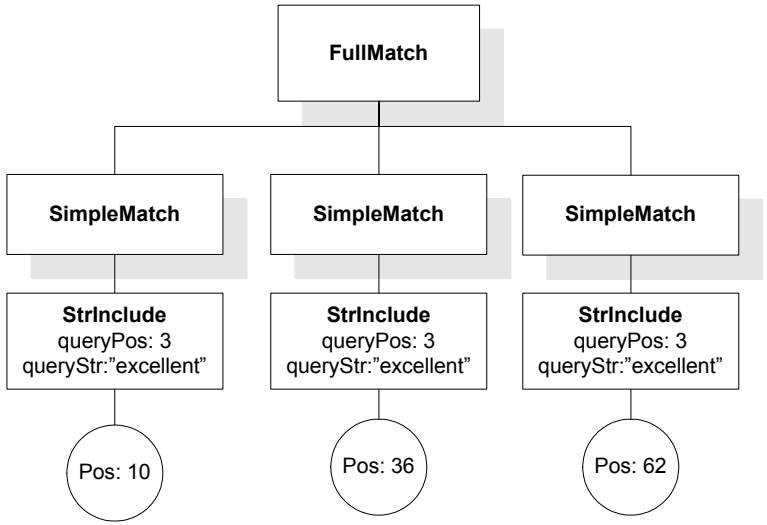
Step 1: Evaluate the *FTStringSelection* `"Mustang"`



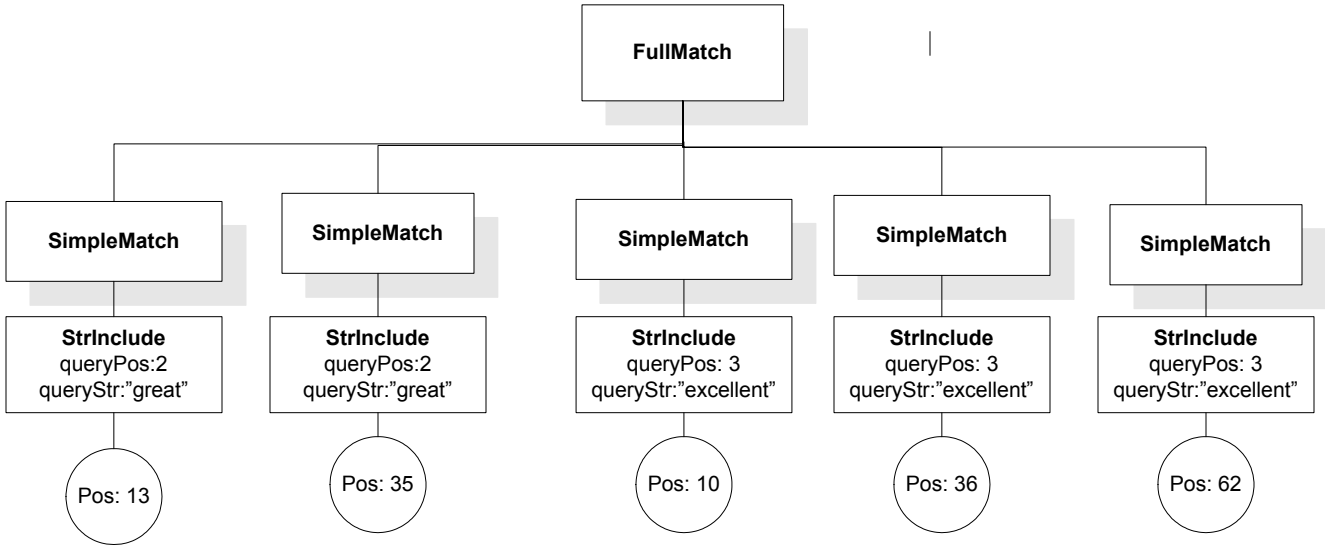
Step 2: Evaluate the *FTStringSelection* `"great"`



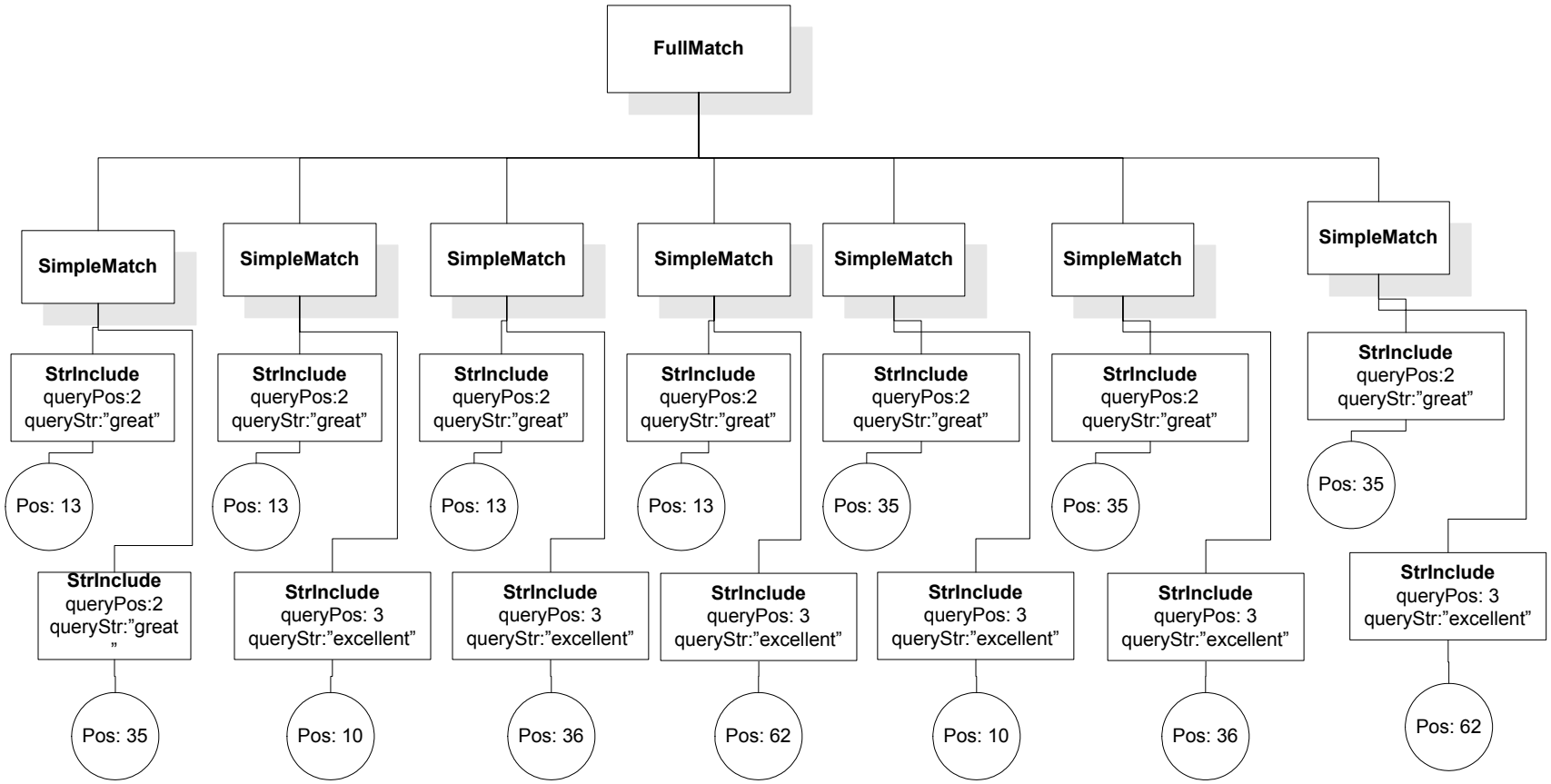
Step 3: Evaluate the *FTStringSelection* `"excellent"`



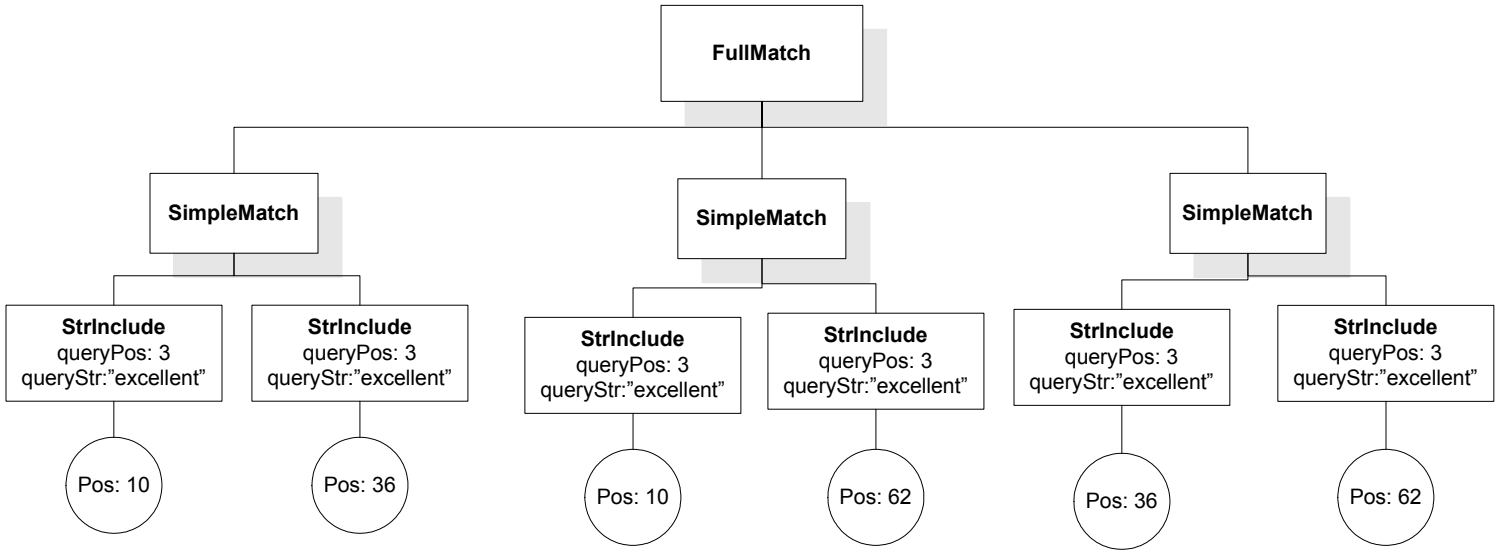
Step 4 - Apply the *FTOrSelection* `("great" || "excellent")`**: form the union of the *SimpleMatch*'es**



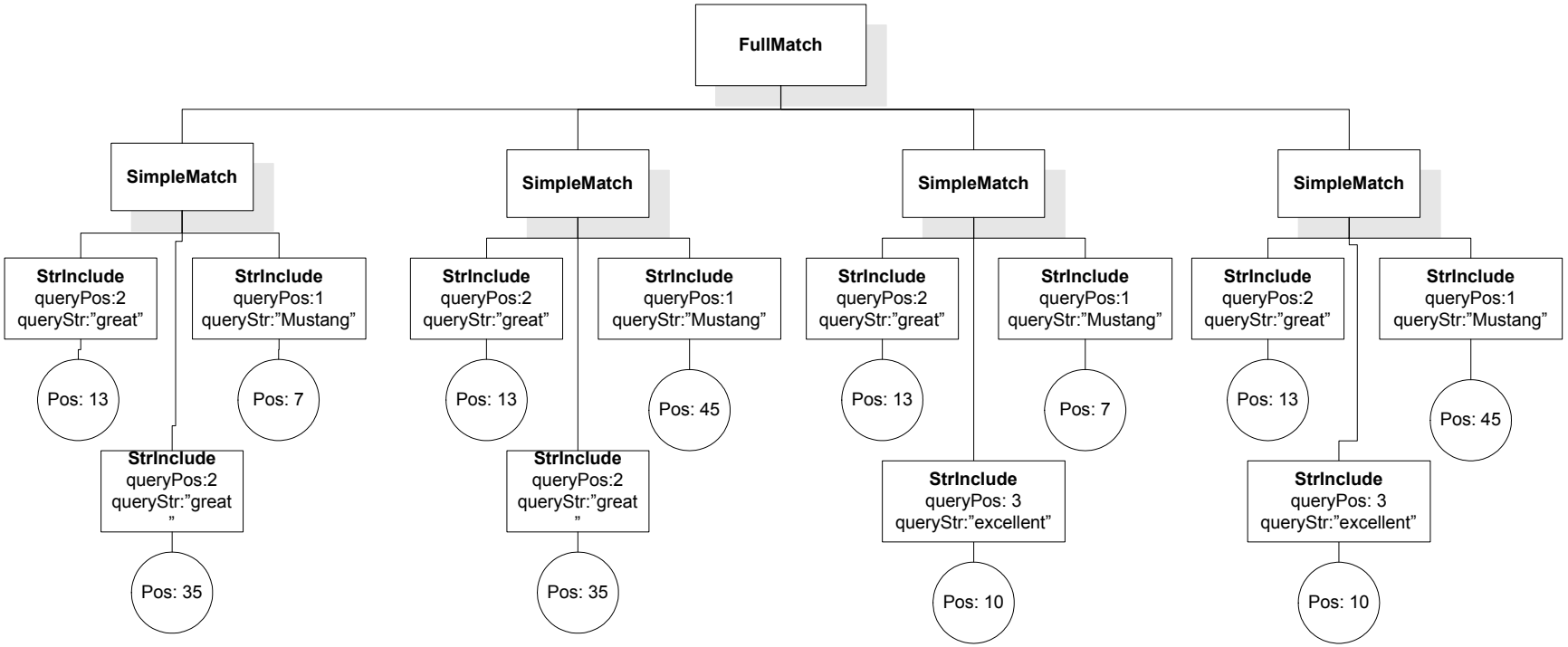
Step 5 - Apply the *FTTimesSelection* `("great" || "excellent") at least 2 occurrences` **: form 2-tuples (couples) of *SimpleMatch*'es**



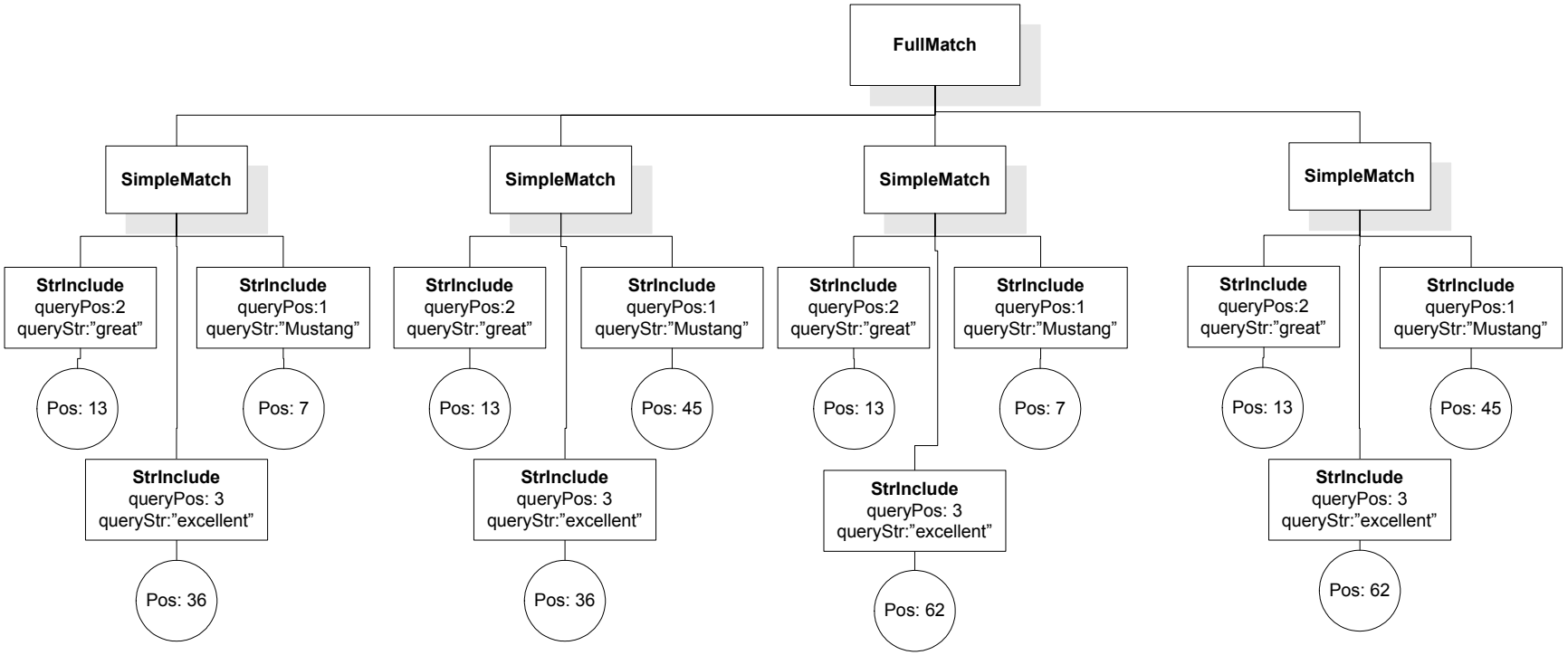
Continues on next page


FullMatch
SimpleMatch
SimpleMatch
SimpleMatch
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
Pos: 10
Pos: 36
Pos: 10
Pos: 62
Pos: 36
Pos: 62

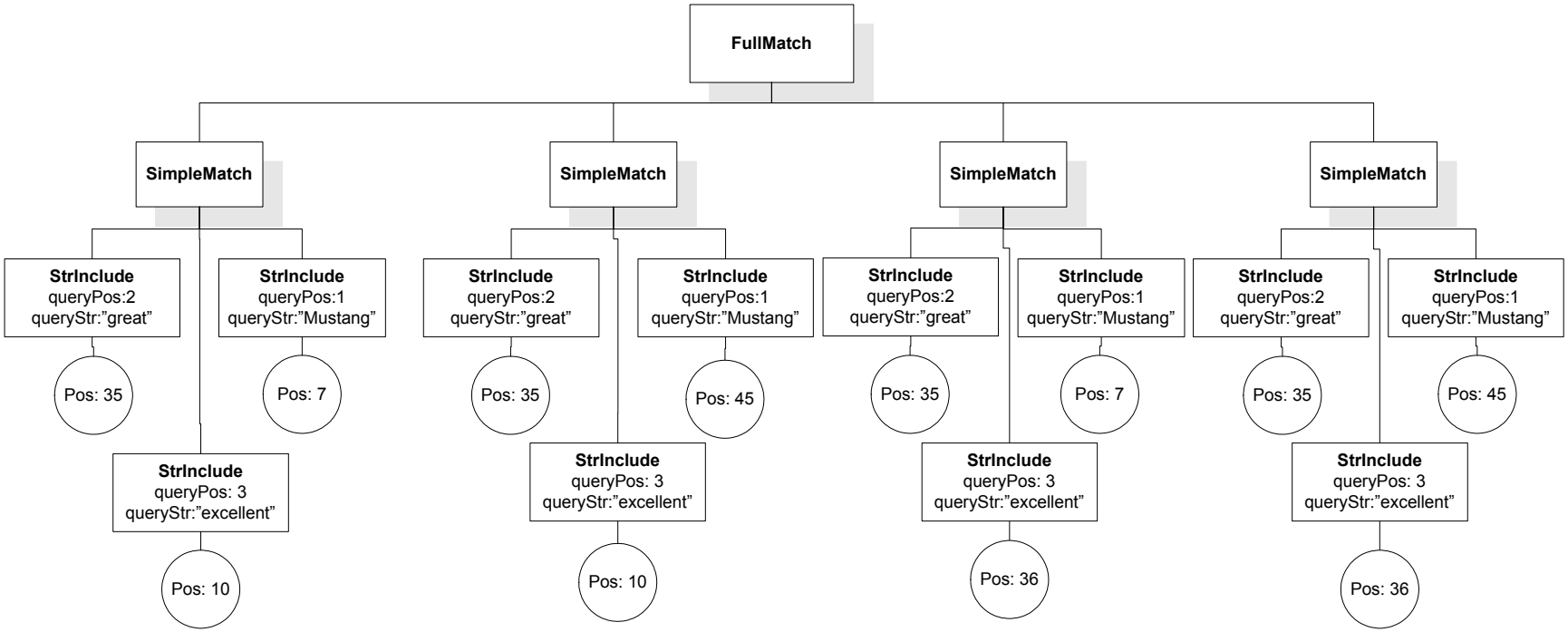
Step 6 - Apply the FTAndConnective `"Mustang" && (("great" || "excellent") at least 2 occurrences)`**: form the "Cartesian product" of *SimpleMatch*'es**



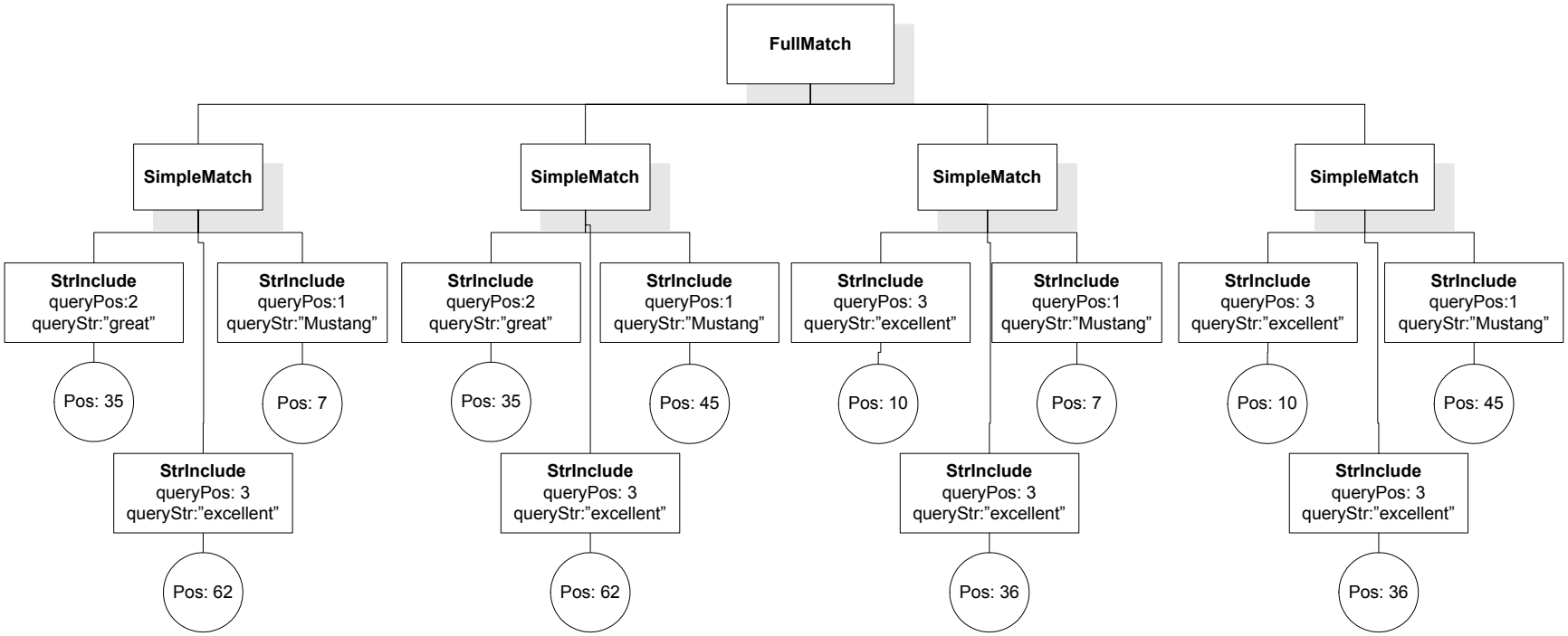
Continues on next page



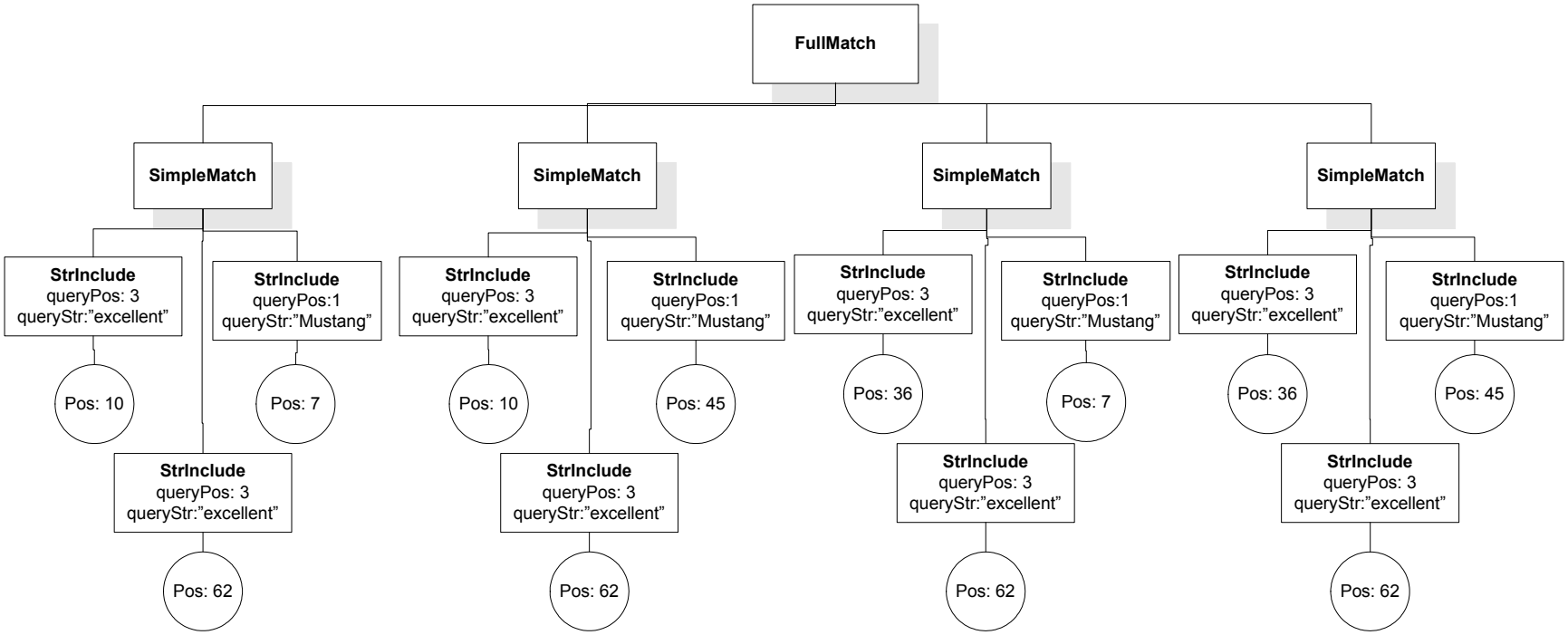
Continues on next page



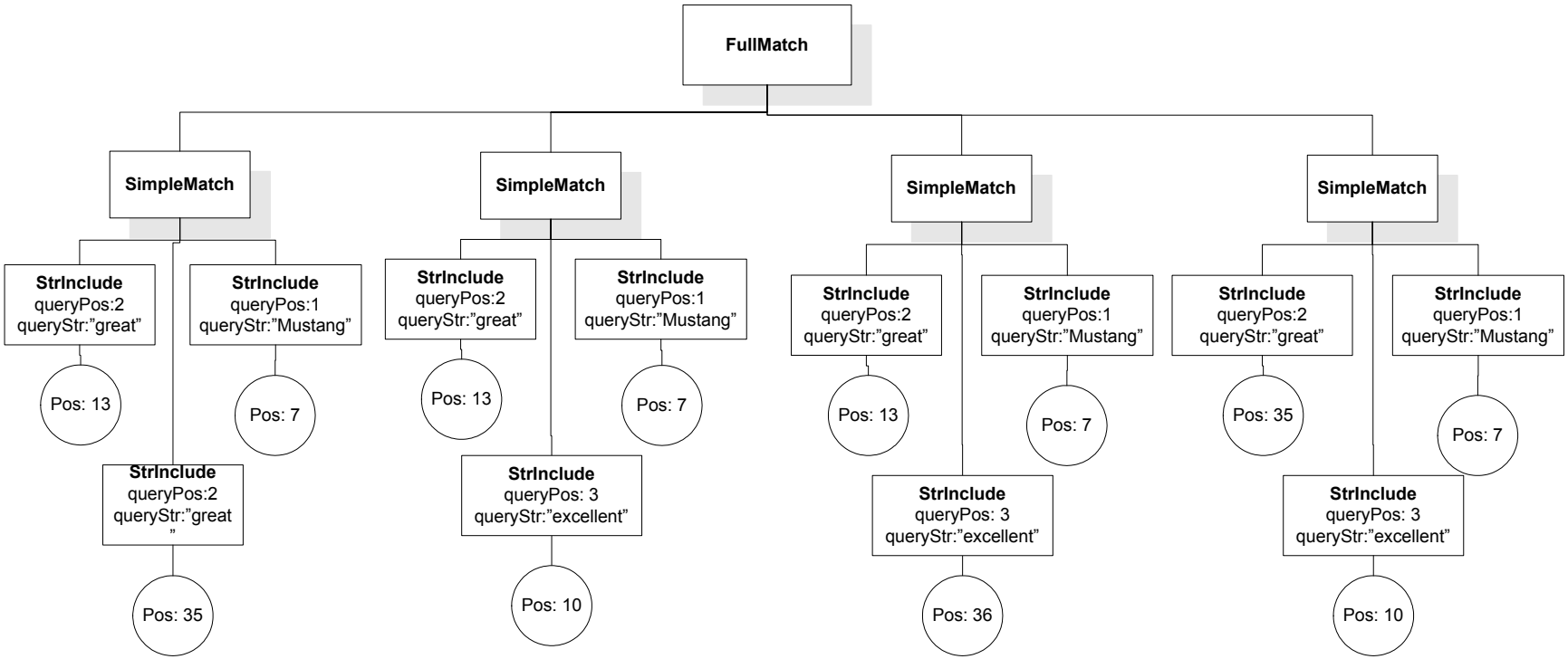
Continues on next page



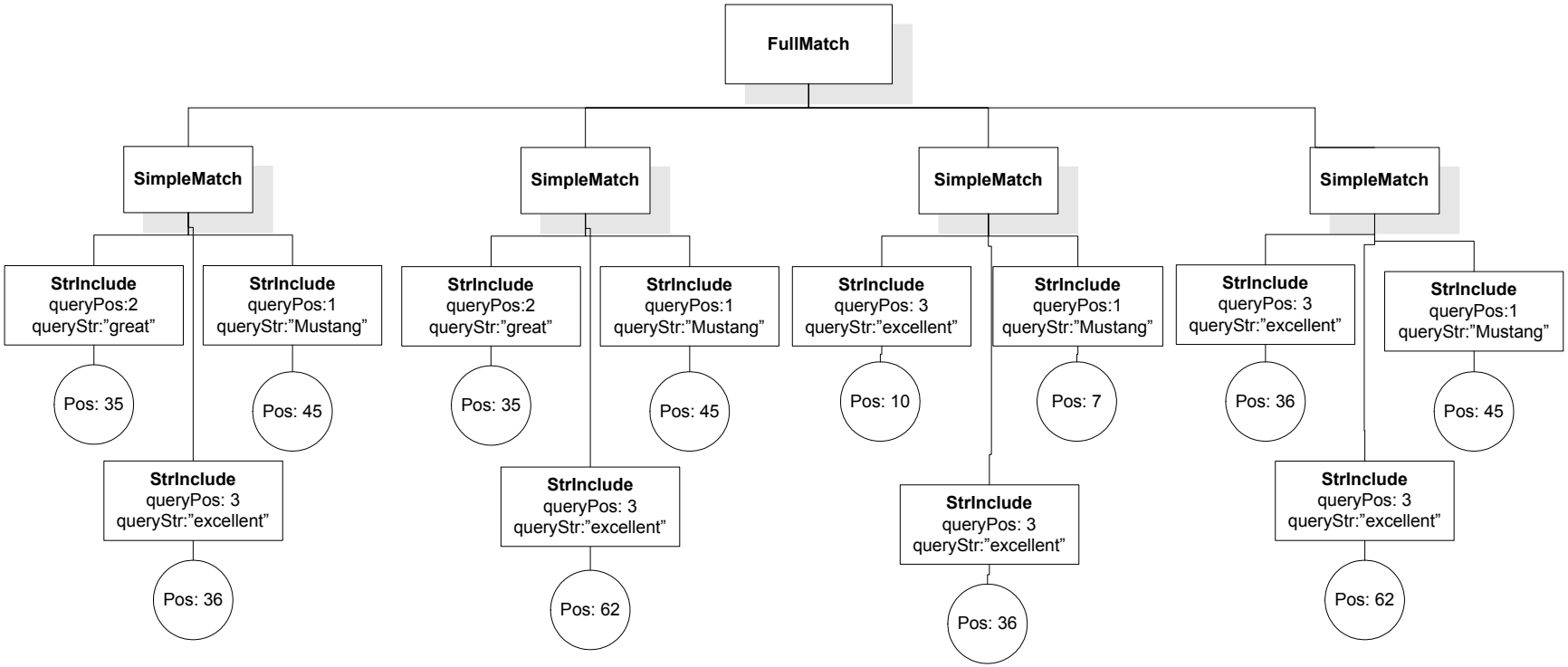
Continues on next page


FullMatch
SimpleMatch
SimpleMatch
SimpleMatch
SimpleMatch
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos:1
queryStr:"Mustang"
Pos: 10
Pos: 7
Pos: 62
Pos: 45
Pos: 36

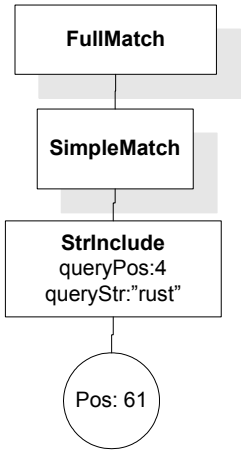
Step 7 - Apply the *FTWindowSelection* `("Mustang" && (("great" || "excellent") at least 2 occurrences)) window at most 30`**: filter out *SimpleMatch*'es for which the window is not less than or equal to 30**



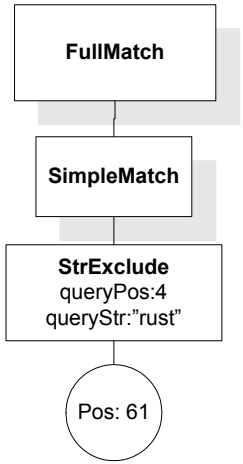
Continues on next page


FullMatch
SimpleMatch
SimpleMatch
SimpleMatch
SimpleMatch
StrInclude
queryPos:2
queryStr:"great"
StrInclude
queryPos:1
queryStr:"Mustang"
StrInclude
queryPos:2
queryStr:"great"
StrInclude
queryPos:1
queryStr:"Mustang"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos:1
queryStr:"Mustang"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos:1
queryStr:"Mustang"
Pos: 35
Pos: 45
Pos: 35
Pos: 45
Pos: 10
Pos: 7
Pos: 36
Pos: 45
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
StrInclude
queryPos: 3
queryStr:"excellent"
Pos: 36
Pos: 62
Pos: 36
Pos: 62

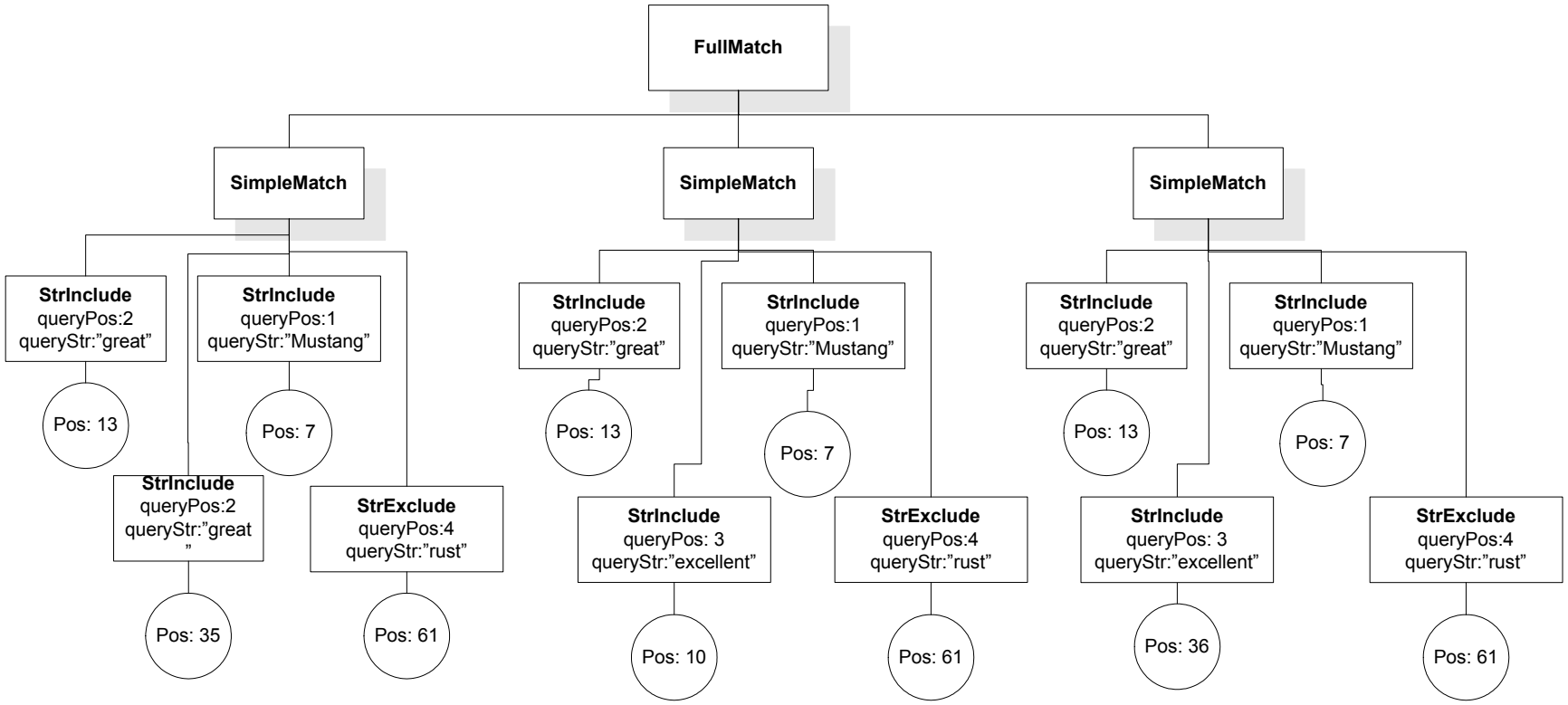
Step 8 - Match *FTStringSelection* `"rust"`



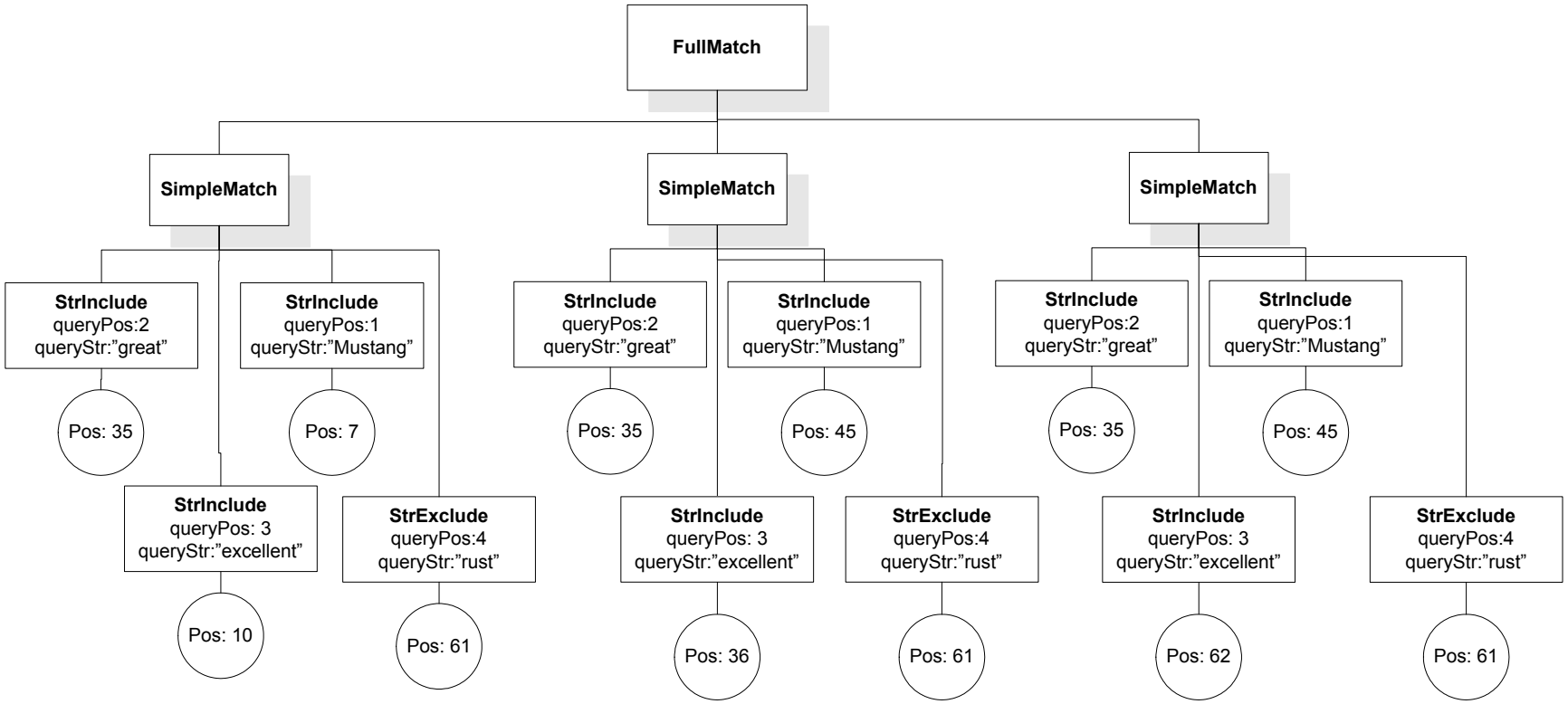
Step 9 - Apply FTNegation `!` `"rust"`: transform the StringInclude into StringExclude



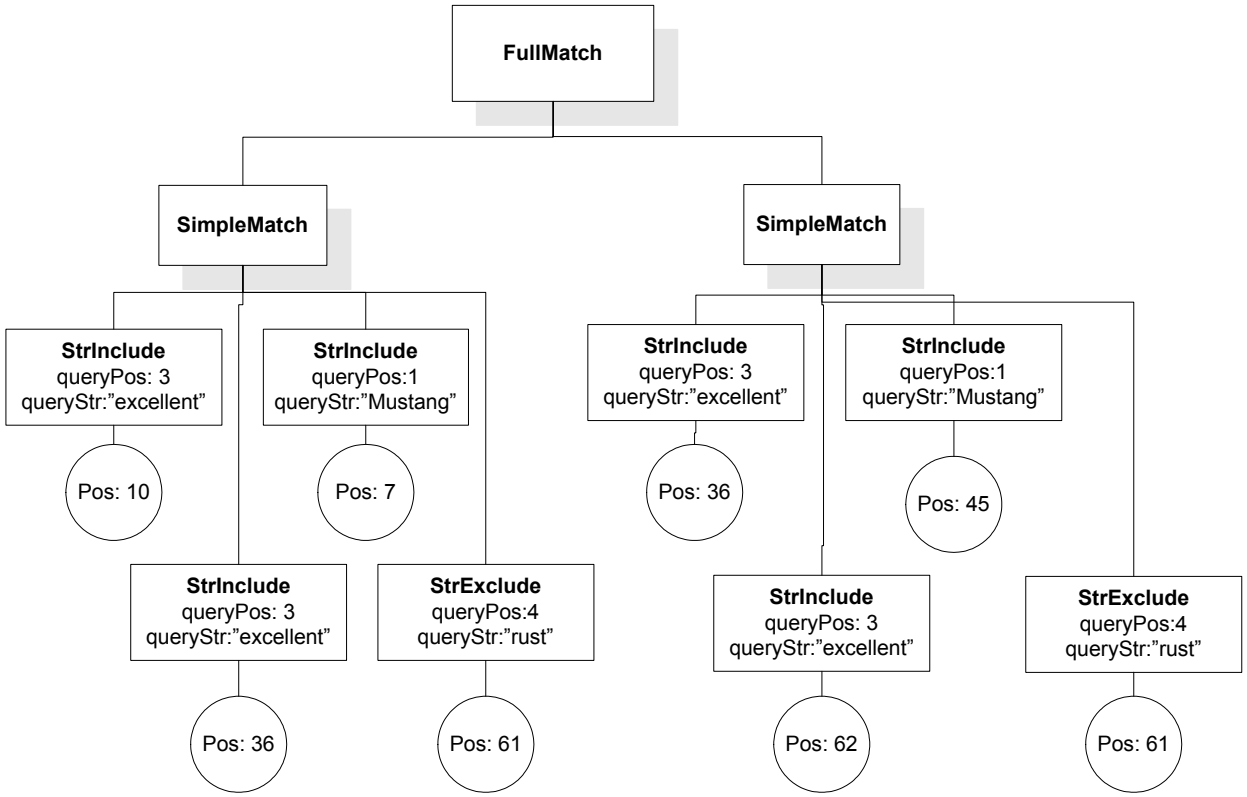
Step 10 - Apply the *FTAndConnective* `(("Mustang" && (("great" || "excellent") at least 2 occurrences)) window at most 30) && ! "rust"`**: form the "Cartesian product" of the *SimpleMatch*'es**



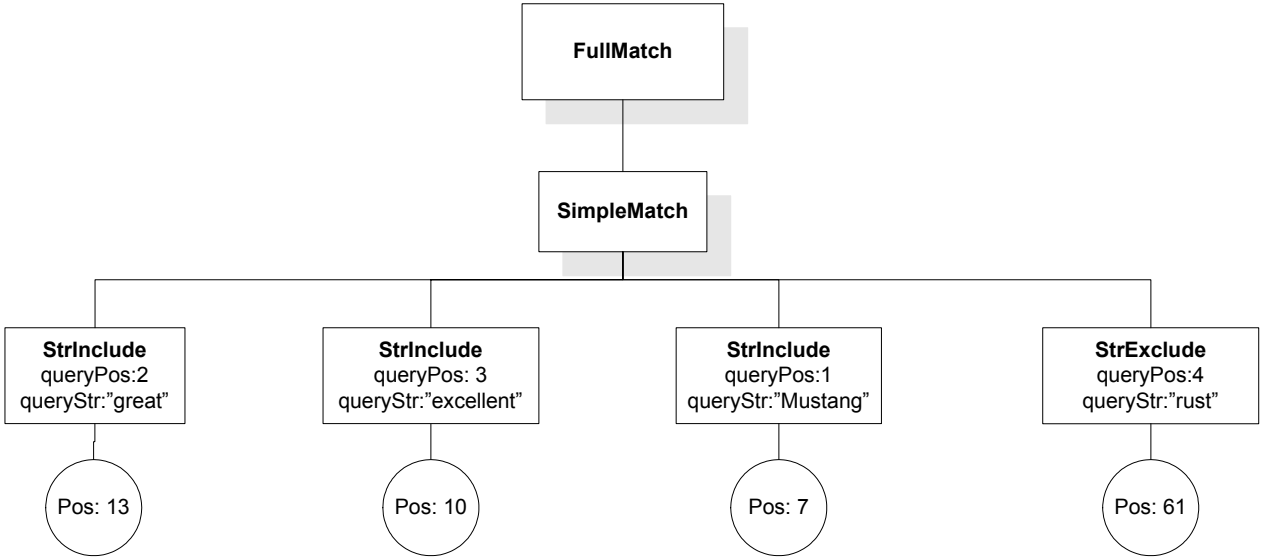
Continues on next page



Continues on next page


FullMatch
SimpleMatch
SimpleMatch
StrInclude
queryPos: 3
queryStr:”excellent”
StrInclude
queryPos:1
queryStr:”Mustang”
StrInclude
queryPos: 3
queryStr:”excellent”
StrInclude
queryPos:1
queryStr:”Mustang”
Pos: 10
Pos: 7
Pos: 36
Pos: 45
StrInclude
queryPos: 3
queryStr:”excellent”
StrExclude
queryPos:4
queryStr:”rust”
StrInclude
queryPos: 3
queryStr:”excellent”
StrExclude
queryPos:4
queryStr:”rust”
Pos: 36
Pos: 61
Pos: 62
Pos: 61

Step 11: Apply the final *FTScopeSelection* – filter out *SimpleMatch*'es whose positions are not within the same node



This is the final FullMatch!

7. References

[1] XQuery Language. The W3 Consortium. http://www.w3.org/TR/xquery/

[2] XQuery 1.0 and XPath 2.0 Data Model. The W3 Consortium. http://www.w3.org/TR/xpath-datamodel/

[3] XQuery and XPath Full-Text Use Cases. The W3 Consortium. http://www.w3.org/TR/xmlquery-full-text-use-cases/